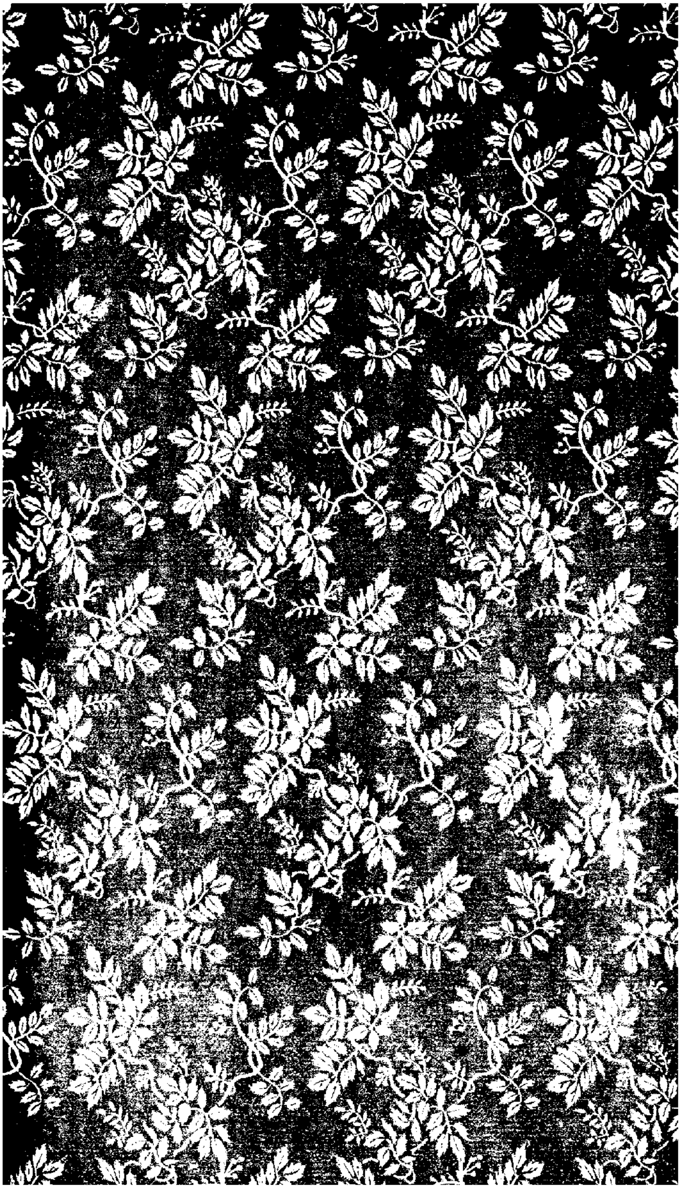

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ERRATA

Page 151, line 25, "Sphacropsideae" should read "Sphaerioidaceae."

Page 130, "*Penicillium camemberti*, var. *rogri*" should read "*Penicillium camemberti*, var. *rogeri*."

Page 296, Pl. XXXIII, figs. 3 to 15. The magnification of the illustrations should be half that stated in the legend.

Page 303, line 17, "Plate XXXVI, figures 1 to 4" should read "Plate XXXVII, figures 1 to 4" and "In figure 4, Plate XXXVI" should read "In figure 4, Plate XXXVII."

Page 318, Table IV, under head "General remarks," "rooting" should read "shooting."

Page 337, Table II, 4th column, "Phenolized defibrinated blood 3895 (unwashed)" should read "Phenolized defibrinated blood 3895."

Page 377, last line, 2d paragraph, "winged" should read "wingless."

Page 384, Table I, 6th column, "Current (milliampere minutes)" should read "Current (milliamperes)."

Page 388, line 13 from bottom, omit "with humidity at 57."

Page 419, line 25, "The twelve-spotted (or squash) lady beetle" should read "The squash lady beetle."

Page 419, line 28, "(*Crepidodera cucumeris*)" should read "(*Epitrix cucumeris*)."

Page 459, lines 2 and 24, omit "Three."

Page 471, line 4, "*Aleurodes mori* Ckll." should read "*Aleurodes mori*, var. *arizonensis* Ckll."

Page 762, Table I, first column, "*Medicago arbica*" should read "*Medicago arabica*."

Page 791, Table XIV, 1st column, "(p. 23)" should read "(p. 783)."

Page 865, legend under figure 5, "The solid black line, etc.," should read "The hatched line."

Page 866, legend under figure 6, omit sentences 2 and 3.

Page 881, line 6 from bottom, "April" should read "May."

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RELATION OF CARBON BISULPHID TO SOIL ORGANISMS AND PLANT GROWTH[1]

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INTRODUCTION

In a previous publication concerning the action of carbon bisulphid (CS_2) on bacteria and plants data were presented to show the beneficial effect of this substance on the soil flora (1).[2] The increased plant growth following the addition of carbon bisulphid in many cases is enormous. For example, a small application often causes an increase in yield from 100 to 200 per cent. It is impossible to account for this remarkable gain on the assumption that the only action of the carbon bisulphid is that of added plant food. It was found, as has been noted by many investigators (5, 6, 11, 12), that this volatile antiseptic exerts a very decided effect on the micro-organisms of the soil. As measured by plate counts, there is at first usually a great decrease in numbers, followed by a period of excessive increase, the total numbers far exceeding those that ordinarily exist. In certain cases carbon bisulphid has not only failed to cause an increase in plant growth, but has, on the contrary, caused a decrease.

Search has been made by many investigators for a satisfactory explanation of this peculiar action of carbon bisulphid. Many theories have been advanced. Concerning these theories so much has been written that a detailed discussion of the literature seems unnecessary. Indeed, it would be impossible within the limited scope of this paper to present a summary of the various explanations. One point is very prominent in nearly all of the publications: The action of carbon bisulphid is varied. Because of the interest attached to this problem, it was arranged to study some of the factors that might influence the action of carbon bisulphid. The experiments described in this paper are discussed under three main heads: First, the effect of varying amounts of carbon bisulphid; second, the effect of carbon bisulphid on various plants; and third, the effect of carbon bisulphid in various soils. In all of this work fresh field soil and commercial carbon bisulphid were used. Some of the experiments represent a combined study of the effect on both the lower and higher forms of plant life.

[1] Published with permission of the Director of the Wisconsin Agricultural Experiment Station.

[2] Reference is made by number to "Literature cited," p. 18-19.

EXPERIMENTAL METHODS

Commercial carbon bisulphid was poured into small holes in the soil, and these were covered immediately. The soil was sieved and potted in 2-gallon jars and the moisture maintained at half saturation. Changes in the soil flora were determined at regular intervals by plate counts of the number of bacteria and dilution counts of the number of active protozoa. The formation of ammonia and nitrates was measured at regular intervals.

The following plants were used: Buckwheat (*Fagopyrum fagopyrum*), clover (*Trifolium pratense*), corn (*Zea mays*), mustard (*Sinapis alba*), oats (*Avena sativa*), and rape (*Brassica napus*). In many of the experiments a first and a second crop were grown.

EFFECT OF CARBON BISULPHID ON THE NUMBER AND ACTIVITY OF SOIL ORGANISMS

Eight jars were filled with Miami silt-loam soil from the Experiment Station farm. These were arranged in duplicate and treated as follows: (1) Control, untreated; (2) 2 per cent of carbon bisulphid; (3) 2 per cent of carbon bisulphid, evaporated; (4) 2 per cent of carbon bisulphid, evaporated, and reinoculated with 5 per cent of the original soil.

Twenty-four hours after treatment the soil in the evaporated series was spread out on sterile paper and the volatile antiseptic allowed to escape. At the end of the second 24-hour period the soil was put back into the jars. In order to prevent any contamination, the jars were covered with a double layer of cheesecloth and nonabsorbent cotton. This cover should allow free access of air without much danger of contamination. At regular intervals the covers were removed and samples drawn for analysis. The results of these determinations are presented in Tables I and II.

NUMBER OF ORGANISMS

BACTERIA.—In Table I are shown the number of bacteria in 1 gm. of soil at different times and under the different conditions.

TABLE I.—*Effect of carbon bisulphid on number of bacteria*

Time.	Bacteria per gram of dry soil.			
	Control.	2 per cent of carbon bisulphid.	2 per cent of carbon bisulphid evaporated.	2 per cent of carbon bisulphid evaporated + 5 per cent of soil from control.
Days.				
1	11, 496, 000	1, 965, 000	2, 260, 000	2, 358, 000
3	22, 010, 000	23, 975, 000	8, 254, 000	12, 480, 000
5	20, 635, 000	25, 253, 000	27, 416, 000	95, 499, 000
9	14, 739, 000	36, 651, 000	61, 904, 000	....
13	16, 115, 000	90, 473, 000	98, 850, 000	80, 420, 000
21	19, 508, 000	60, 149, 000	71, 257, 000	52, 495, 000
25	18, 272, 000	68, 276, 000	86, 483, 000	64, 570, 000
29	15, 346, 000	90, 645, 000	84, 272, 000	38, 495, 000
60	12, 372, 000	58, 101, 000	60, 000, 000	30, 000, 000

At first the antiseptic causes a great reduction in the number of organisms capable of developing on Heyden agar. The period of depression lasts for only a short time—in this experiment about five days. From that time until the end of the test the number of organisms in the treated series far exceeded that of the control. The highest number in the carbon bisulphid evaporated and unevaporated soil occurred about the thirteenth day; while the carbon bisulphid evaporated soil plus control soil gave the highest count on the fifth day. At the time of the last count, 60 days after carbon bisulphid was added, the organisms in the treated series far exceeded those in the original soil. Apparently the effect of carbon bisulphid on the number of bacteria is noticeable for a long period of time.

If the results of the counts with carbon bisulphid unevaporated are compared with those of carbon bisulphid evaporated, it appears that no very marked difference exists. The greatest reduction in numbers occurred in soils with the carbon bisulphid evaporated. It is significant that soil with carbon bisulphid evaporated should prove more injurious to micro-organisms than the unevaporated. This agrees with Gainey (2, p. 592), who reports that the combined effect of the two processes seemed more injurious to nitrification than treatment with carbon bisulphid unevaporated.

After the thirteenth day the treated and reinoculated soil did not show as many organisms as the treated series. This difference is shown very distinctly in Plate I, which is reproduced from a photograph of a number of colonies developing on agar. Four parallel plates were made from the same dilution of each soil.

On this date samples were also drawn for ammonification tests. The purpose of this was to measure the rate of the decomposition of casein in the various series, and 1 per cent of casein was added to the soil and the ammonia determined after 12 and 24 hours. The beneficial effect of carbon bisulphid on ammonification is very evident. If after 12 hours the untreated is 100, then carbon bisulphid unevaporated is 154, carbon bisulphid evaporated is 212, and carbon bisulphid reinoculated is 190.

After 24 hours the untreated is equal to 100, carbon bisulphid unevaporated is 149, carbon bisulphid evaporated is 171, and carbon bisulphid reinoculated is 153. The data show very clearly that casein is decomposed more rapidly in treated than in untreated soils. This difference is most prominent in the 12-hour tests.

Protozoa.—Counts at the beginning showed the presence of protozoa in dilutions representing 1 to 1,000 gm. of soil (13, p. 626). Two weeks after treatment the soils were recounted. At this time numerous small flagellates were found in dilutions of 1 to 1,000. It is evident that the different treatments with carbon bisulphid had not seriously injured this group of organisms.

AZOTOBACTER.—One month after treatment with carbon bisulphid, qualitative tests were made. The Azotobacter organisms were found in all soils. The brown film of Azotobacter from the treated soils was not so profuse as that from the original soil.

ALGÆ.—In order to estimate the number of algæ, dilution tests were made. These cultures were incubated for 30 days. The smaller forms were found in great numbers in all of the soils.

The important facts in these data are (1) that the volatile antiseptic fails to remove these larger soil organisms and (2) that the smaller forms of bacteria are only temporarily reduced. The decrease in numbers is soon followed by a period of excessive growth.

ACTIVITY OF ORGANISMS

A rapid multiplication of bacteria should naturally be followed by a parallel increase in decomposition products. Accordingly samples for analysis were drawn from the jars used in the previous experiment. The results of these periodic analyses are presented in Table II.

TABLE II.—*Effect of carbon bisulphid on ammonia and nitrate content of soil*

Time.	Nitrogen per 100 gm. of dry soil.							
	Ammonia.				Nitrate.			
	Control.	2 per cent of carbon bisulphid.	2 per cent of carbon bisulphid evaporated.	2 per cent of carbon bisulphid evaporated+5 per cent of soil from control.	Control.	2 per cent of carbon bisulphid.	2 per cent of carbon bisulphid evaporated.	2 per cent of carbon bisulphid evaporated+5 per cent of soil from control.
Days.	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*
At beginning	1. 60	1. 60	1. 60	1. 60	2. 66	2. 66	2. 66	2. 66
30	1. 68	5. 27	5. 41	4. 71	3. 35	2. 50	2. 00	5. 55
45	2. 38	8. 40	7. 70	4. 90	3. 75	2. 70	2. 50	5. 66
60	2. 59	5. 43	5. 32	2. 31	4. 00	2. 81	2. 50	4. 50
75	1. 85	5. 60	....	2. 10	3. 20	2. 40	2. 60	5. 00
90	2. 94	4. 06	4. 06	2. 24	4. 00	5. 00	3. 32	6. 66

In the soils treated with carbon bisulphid there is a very decided accumulation of ammonia nitrogen. If the figures of Table I are compared with those of Table II, ammonia production, it will be seen that an increase in the number of bacteria within a certain range results in a gain in ammonia. After 30 days the amount of ammonia nitrogen in the treated soils averaged more than three times that in the original soil. After 60 days the ammonia content in the carbon bisulphid and carbon bisulphid evaporated soil was about double that of the control, while in the carbon bisulphid evaporated plus 5 per cent fresh soil it was

less. From the data it appears that reinoculation prevents large accumulations of ammonia. This is no doubt due to the oxidation of ammonia by the nitrifying bacteria. The figures of the last column (nitrate accumulation) support this statement. A stimulation of ammonification is still noticeable at the end of 3 months.

The nitrate-forming bacteria apparently do not recover so rapidly from carbon bisulphid treatment as the ammonia-producing organisms; consequently, there is no increase in nitrates until the end of 3 months. An exception to this is noted in the reinoculated soil. Here the activity of the nitrifying bacteria is evident 30 days after inoculation.

In order to ascertain, as nearly as possible, the effect of carbon bisulphid on the soluble nitrogen of the soil, the figures of Table II, ammonia and nitrate nitrogen, were combined in Table III.

TABLE III.—*Effect of carbon bisulphid on soluble nitrogen*

Time.	Ammonia and nitrate nitrogen per 100 gm. of dry soil.			
	Control.	2 per cent carbon bisulphid.	2 per cent carbon bisulphid evaporated.	2 per cent carbon bisulphid evaporated + 5 per cent of soil from control.
Days.	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*
At beginning	4.26	4.26	4.26	4.26
30	5.03	8.47	7.41	10.26
45	5.13	11.10	10.20	10.56
60	6.59	8.24	7.82	6.87
75	5.05	8.00	....	7.10
90	6.94	9.06	7.38	8.90

From the data in this table it is very evident that carbon bisulphid causes a large increase in ammonia and nitrate nitrogen. There seems to be very little difference between the effect of the various treatments of carbon bisulphid on the formation of ammonia and nitrate nitrogen. When compared with the control soil, it will be seen that 45 days after treatment the carbon-bisulphid soils contain more than twice as much soluble nitrogen. The higher ammonia and nitrate content is very marked 90 days after treatment. A repetition of this experiment gave similar results.

A review of the data in Tables II and III shows very clearly that carbon bisulphid in Miami soil increases the total soluble nitrogen—namely, ammonia and nitrates. One interesting fact that appears from a comparison of the ammonia and nitrate content is that these two substances are to a certain degree inversely proportional.

EFFECT OF CARBON BISULPHID ON THE HIGHER AND LOWER FORMS OF PLANT LIFE

From the results of the preceding experiments it seems that carbon bisulphid should exert a beneficial effect on the growth of higher plants. At first this should be most marked with ammonia-feeding plants, and later with nitrate-feeding plants. Unfortunately it is not possible to secure plants that feed entirely on nitrates or ammonia. For this reason it was thought best to study the relation of carbon bisulphid to the growth of several different plants. Accordingly a combination study of the effect of carbon bisulphid on higher plants and on bacteria was made. A wide range of soil types, as well as different higher plants, was used.

Before entering upon a study of the relation of carbon bisulphid to soil type and various plants, it was desired to obtain some idea of the influence of various amounts of carbon bisulphid on plant growth. The procedure was as follows: Ten kgm. of field soil (Miami silt loam) were placed in each of sixteen 2-gallon jars. The carbon bisulphid was added in varying amounts, from 0.5 per cent to 2 per cent. It was poured into holes in the soil. These holes were closed immediately and the water increased to half saturation. In order to overcome the injurious effect of carbon bisulphid, the jars were then allowed to stand for two weeks before planting.

CORN AND MUSTARD IN MIAMI SILT LOAM

The results of the test with corn and mustard are given in Table IV. It is evident from the data of the table that these plants do not respond alike to carbon bisulphid.

TABLE IV.—*Effect of varying amounts of carbon bisulphid on the growth of corn and mustard*

No.	Soil.	Carbon bisulphid added.	Weight of corn.			Weight of mustard.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami	Control.	75	20	22.5	58	9.5	9.25
2	do	Control.	80	25		49	9	
3	do	0.5	82	18	19.5	69	13	12.50
4	do	.5	83	21		72	12	
5	do	1	132	28	19.5	95	13	12.50
6	do	1	22	11		75	12	
7	do	2	85	21	24	105	16	16.50
8	do	2	125	27		112	17	

In all concentrations except 2 per cent, carbon bisulphid injured the growth of corn. Mustard, on the other hand, was greatly benefited by the carbon-bisulphid treatment. An increased growth was observed from all concentrations. The maximum gain was noted with 2 per cent of carbon bisulphid. This beneficial effect on mustard is very evident from Plate II, figure 1. If this increase in growth is due to the larger

amount of soluble nitrogen as ammonia or nitrate, then corn and mustard should behave much alike. The nitrogen-feeding power of these plants has been studied by Krüger (8), Gerlach and Vogel (3), and others. It is supposed that both corn and mustard are heavy nitrogen-feeding crops, able to take nitrogen either in the form of ammonia or nitrate.

BUCKWHEAT, CORN, AND OATS IN MIAMI SILT LOAM

In order to decrease the factor of individual variation, four parallel jars of Miami silt loam were used in each series in the following experiment. For the second crop these were subdivided into sets of two each. After the first crop was harvested, the soil and roots were thoroughly mixed and the jars replanted. The rotation was as follows: First crop, buckwheat; second crops, corn and mustard; first crop, corn; second crop, buckwheat; first crop, oats; second crops, corn and mustard. In Tables V, VI, and VII are presented the results of these experiments.

Table V.—*Effect of carbon bisulphid on the growth of buckwheat and corn*

No.	Soil.	Carbon bisulphid added.	Weight of first crop, buckwheat.			Weight of second crop, corn.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami	Control.	90	15.5	19	152	28.5	31
2	...do...	Control.	97	18		160	33.5	
3	...do...	Control.	121	22.2		......	......	
4	...do...	Control.	126	20.5		......	......	
5	...do...	2	124	23	24.5	169	34	32.7
6	...do...	2	145	26.5		136	31.5	
7	...do...	2	127	23		......	......	
8	...do...	2	126	25.5		......	......	

The yields of buckwheat and corn are given in Table V. The weights of the mustard were lost. Buckwheat gave an increase in the treated soil, while corn (the second crop) did not show any improvement. Determinations of ammonia present at the time the buckwheat was cut (three months after treatment) resulted as follows: Ammonia—if control is 100, then carbon bisulphid treated is 192. Nitrate—if control is 100, then carbon bisulphid treated is 28. The antiseptic increases ammonia, but decreases the nitrate content of soil. The results of investigation show that buckwheat feeds largely on nitrate nitrogen (9), while corn is supposed to be able to take its nitrogen in the form of ammonia. A difference in nitrogen-feeding power can not be used to explain the unequal behavior of these plants toward carbon bisulphid. Although the weights of the mustard crop were not kept, the action of the carbon bisulphid was evident. There was a decided gain in the growth of plants in the treated series.

From the data of Table VI it is obvious that carbon bisulphid has very little effect on corn (first crop) or buckwheat (second crop).

TABLE VI.—*Effect of carbon bisulphid on the growth of corn and buckwheat*

No.	Soil.	Carbon bisulphid added.	Weight of first crop, corn.			Weight of second crop, buckwheat.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami	Control.	480	85	84.7	115	26	23.5
2	...do...	Control.	440	82		125	27	
3	...do...	Control.	500	90		100	22	
4	...do...	Control.	410	82		95	19	
5	...do...	2	380	77	83	128	27	20.5
6	...do...	2	460	85		87	17	
7	...do...	2	410	83		95	20	
8	...do...	2	460	86		87	18	

Table VII gives the effect of this volatile antiseptic on oats (first crop) and corn (second crop). The former showed an increase in growth in the treated soil; the latter was not affected.

TABLE VII.—*Effect of carbon bisulphid on the growth of oats and corn*

No.	Soil.	Carbon bisulphid added.	Weight of first crop, oats.			Weight of second crop, corn.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami	Control.	172	46.5	48.3	166	40	36
2	...do...	Control.	184	51		132	31	
3	...do...	Control.	171	46.7		118	29	
4	...do...	Control.	182	49		180	45	
5	...do...	2	200	59	57.8	155	37	37
6	...do...	2	205	59		161	38	
7	...do...	2	197	57.7		152	37	
8	...do...	2	192	57.5		135	36	

A general consideration of the data shows that corn in this soil type is apparently indifferent toward carbon bisulphid. Buckwheat, oats, and mustard were all benefited by the antiseptic.

BUCKWHEAT, MUSTARD, OATS, AND CORN IN DIFFERENT SOILS

The experiment with buckwheat, mustard, corn, and oats was a combination study of the effect of carbon bisulphid on bacterial activity and plant growth in three different soils. The first series contained Miami silt loam, the second series Miami soil diluted one-half by volume with sand, and the third series sand alone. According to chemical analysis, Miami silt loam is fairly rich in organic matter, nitrogen, potassium, and phosphorus. Of the three fertilizing elements, phosphorus perhaps is present in the smallest amount. The quantity of soil and its treatment was similar to that of the preceding experiment except that the treated jars were kept tightly covered with parchment paper. One month after the carbon bisulphid was added, these were removed. By

this means it was hoped to prevent a rapid volatilization of the antiseptic. The jars were not planted until three months after treatment.

At the beginning and at intervals of one, two, and three months bacterial activity was measured. Naturally, under the conditions of this experiment, carbon bisulphid proved very drastic. A great reduction in the number of bacteria, without any increase until the second month, was noted. The relation of carbon bisulphid to the number of bacteria was about the same in all three series. In the more compact type, Miami silt-loam soil, the carbon bisulphid proved most injurious to numbers, and consequently the period of increase was much later. Of the three soils, the treated sand showed the greatest proportional gain in number of bacteria.

Because of the severe nature of the carbon-bisulphid treatment, it was thought that probably the protozoa would be destroyed or the number greatly diminished. This was not the case, however, as protozoa were found in great numbers in both the treated and untreated soil.

Three months after treatment the jars were divided into two series and planted. The weights of the first and second crops are given in Tables VIII and IX.

TABLE VIII.—*Effect of carbon bisulphid on the growth of buckwheat and mustard in different types of soil*

No.	Soil.	Carbon bisulphid added.	Weight of first crop, buckwheat.			Weight of second crop, mustard.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami silt loam	Control.	123	22.5	21.5	12.0	3.4	3.3
2	....do	Control.	107	20.5		10.0	3.3	
3	....do	2	119	25.0	24.0	24.5	5.2	7.3
4	....do	2	114	23.0		41.5	9.5	
5	Half Miami silt loam, half sand.	Control.	74	15.5	15.25	21.0	3.75	3.67
6	....do	Control.	72	15.0		17.0	3.60	
7	....do	2	76	18.0	17.0	21.5	4.5	4.25
8	....do	2	78	16.0		17.0	4.0	
9	Sand	Control.	20	2.5	2.75	4.0	0.4	.45
10	....do	Control.	21	3.0		4.5	0.5	
11	....do	2	21.5	3.0	3.00	17.5	1.2	.90
12	....do	2	21.5	3.0		5.5	.6	

The figures of the buckwheat crop show the same general increase as noted in a previous experiment. Although not great, the gain in the treated series is consistent in all three soils.

The residual crop of mustard responded to a very marked degree to the carbon bisulphid treatment. In Miami silt loam the yield from the treated soil exceeded that of the control by more than 100 per cent. The gain in weight of oats in the treated soils was not so great, while the second-crop corn showed a loss (Table IX).

TABLE IX.—*Effect of carbon bisulphid on the growth of oats and corn in different types of soil*

No.	Soil.	Carbon bisulphid added.	Weight of first crop, oats.			Weight of second crop, corn.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami silt loam	Control.	162	47	47.7	114	25	24
2	.....do	Control.	180	48.5		103	23	
3	.....do	2	157	45.5	49	77	18.5	19.2
4	.....do	2	190	52.5		87	20	
5	Half Miami silt loam, half sand	Control.	82	26.5	27.2	76	16	15
6	.....do	Control.	85	28		56	14	
7	.....do	2	85	27.5	28	52	13	14
8	.....do	2	82	28.5		64	15	
9	Sand	Control.	......	......	......	......	......	......
10	.....do	Control.	18	6	6	12	4	4
11	.....do	2	18	5.8	5.5	14	5	4.5
12	.....do	2	15	5.2		13.5	4	

The results of the nitrate determinations agree with those obtained in previous experiments. At the time of planting the carbon-bisulphid soils were lower in nitrate but higher in ammonia than the original soil.

The data from Tables VIII and IX show that carbon bisulphid has a much more beneficial effect on mustard than on any other crop. Buckwheat and oats are benefited, but not so markedly as mustard. Corn fails to show any improvement from treatment with carbon bisulphid.

EFFECT OF CARBON BISULPHID ON BUCKWHEAT AND RAPE IN VARIOUS SOILS

The five soil types selected for the study of the effect of carbon bisulphid on buckwheat and rape in various soils ranged all the way from a very compact red clay to an open, sandy soil. After treating with 2 per cent of carbon bisulphid the soils were allowed to stand for three months before planting. Bacteria counts and nitrate determinations were made at the beginning and after two and three months. The effect of the carbon bisulphid on the total number of bacteria is very evident. In every case the carbon-bisulphid soil contained the most bacteria. The maximum gain occurred in the clay-loam soil, the minimum in the Norfolk sand. The increase due to the treatment was greatest after two months.

Here, again, the treated soils gave a much lower nitrate content than the controls. It seems safe to say that a rapid increase in numbers of bacteria in a carbon-bisulphid soil is followed by a decrease in the amount of nitrates.

Three months after treatment the soils were planted to buckwheat. Growth was slow at first, especially in the carbon-bisulphid series. The crop was harvested when 60 days old. The results of this experiment are shown in Table X.

TABLE X.—*Effect of carbon bisulphid on the growth of buckwheat in different types of soil*

No.	Soil.	Carbon bisulphid added.	Weight of first crop. Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*
1	Cecil clay	Control.	5	1.2	1.35
2	.....do	Control.	7	1.5	
3	.....do	2	12	3	3.5
4	.....do	2	15	4	
5	Porters clay	Control.	10.5	2	2.75
6	.....do	Control.	14.5	3.5	
7	.....do	2	14.5	3.7	3.15
8	.....do	2	10	2.7	
9	Clay loam	Control.	5.5	1.2	1.6
10	.....do	Control.	12.5	2	
11	.....do	2	28	6.5	7.25
12	.....do	2	30.5	8	
13	Hagerstown loam	Control.	27	6.2	5.6
14	.....do	Control.	25	5	
15	.....do	2	17.5	4.5	6
16	.....do	2	40.5	7.5	
17	Norfolk sand	Control.	32	8.7	9.45
18	.....do	Control.	49.5	10.2	
19	.....do	2	12	3	3.25
20	.....do	2	17.5	3.5	

With one exception, Norfolk sandy soil, the carbon-bisulphid series gave a larger yield. This was most marked in the case of clay-loam soil. The data on plant growth agreed with the plate counts.

The buckwheat was followed by a crop of Dwarf Essex rape. Unfortunately the young rape plants suffered seriously from insects. Although the tissue was too badly infested to save, a decided difference in growth could be seen. The beneficial effect of carbon bisulphid on rape was noted in every soil type.

EFFECT OF CARBON BISULPHID ON VARIOUS CROPS IN ACID SOILS

In order to study the effect of carbon bisulphid on the growth of higher plants in acid soils, a series of experiments was made. Four types of soil were selected for this work: Miami silt loam, Sparta sand, Colby silt loam, and Marshfield peat. The neutral Miami silt loam was used as a check for the acid soils. According to the Truog acidity test, Sparta sand requires 0.5227 gm. of calcium carbonate per 100 gm. of soil, Colby silt loam 1.021 gm., and Marshfield peat 4.43 gm. Four weeks after treatment with carbon bisulphid, the soils were planted.

RED CLOVER

The effect of carbon bisulphid on medium red clover in acid soils is clearly seen from the figures of Table XI. The clover grew luxuriantly in all soils except the untreated acid peat. Two crops were cut. Carbon bisulphid in peat soil caused an enormous gain in the growth of clover. This was very striking in both the first and second crop.

TABLE XI.—*Effect of carbon bisulphid on the growth of red clover in acid soils*

No.	Soil.	Carbon bisulphid added.	Weight of first crop, clover.			Weight of second crop, clover.		
			Green.	Dry.	Average green.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami silt loam	Control.	138	(a)	139	129	19	20
2	.....do	Control.	140			145	21	
3	.....do	2	158		141	168	26	23
4	.....do	2	124			131	20	
5	Sparta sand	Control.	36	(a)	34	58	13	11
6	.....do	Control.	33			48	10	
7	.....do	2	19		25	18	4	6
8	.....do	2	31			43	8	
9	Colby silt	Control.	95	(a)	91	110	20	17
10	.....do	Control.	87			85	14	
11	.....do	2	153		143	108	15	13
12	.....do	2	133			82	12	
13	Peat	Control.	4	(a)	3	6	2.8	2.4
14	.....do	Control.	2			5	2	
15	.....do	2	83		81	53	9	8.7
16	.....do	2	79			46	8.5	

[a] Lost.

Plate II, figure 2, shows the relative growth of clover in the treated and untreated soils.

Each figure for Miami silt loam in Table XI represents the average of triplicate jars. Because of the individual variation, it was decided to use 12 jars for this experiment. Six of these were used as controls and six treated with 2 per cent of carbon bisulphid. It is evident from the data that medium red clover in Miami soil is benefited both in the first and second crop by the antiseptic. In the Sparta sand a decrease was noted with each crop. The Colby silt loam gave a decided increase with the first crop, but not with the second.

Previous tests with these soils showed that the clover bacteria were present in sufficient numbers to produce good inoculation. In view of the large amount of carbon bisulphid applied, it was thought that this substance would probably injure nodule formation. However, examination of the root systems showed this was not the case. The plant roots were thoroughly inoculated, both in the treated and untreated soils. Apparently the plants in carbon bisulphid soils contained the greater number of nodules.

Because of the remarkable action of carbon bisulphid in peat soil, this part of the previous test was repeated. In addition to carbon bisulphid, the effect of flowers of sulphur was studied. If the data in the previous experiment are correct, the carbon bisulphid should greatly increase the growth of clover. A glance at the results in Table XII confirms this statement.

TABLE XII.—*Effect of carbon bisulphid and sulphur on the growth of red clover in peat soil*

No.	Soil.	Treatment.	Weight.		
			Green.	Dry.	Average.
			Gm.	*Gm.*	*Gm.*
1	Peat	Control	34	9	8. 6
2	....do	....do	30	8. 2	
3	....do	1 per cent of carbon bisulphid.	95	21. 5	21. 7
4	....do	....do	110	22	
5	....do	2 per cent of carbon bisulphid.	105	23	21. 2
6	....do	....do	90	19. 5	
7	....do	0.3 per cent of sulphur.	8	3. 5	2. 2
8	....do	....do	4	1	

Carbon bisulphid causes a remarkable increase in the growth of clover on peat soil. There is apparently no decided difference in the action of 1 or 2 per cent of carbon bisulphid. Just why the volatile antiseptic should stimulate so markedly the growth of clover in the peat soil is not known. A more detailed study of the action of carbon bisulphid in peat is now under way. Flowers of sulphur at the rate of 0.3 per cent proved very injurious. In view of the high sulphur content of carbon bisulphid, it was thought that possibly free sulphur in peat might have somewhat the same effect.

CORN AND MUSTARD

The action of carbon bisulphid on corn and mustard in acid soils was studied in an experiment the results of which are given in Table XIII.

TABLE XIII.—*Effect of carbon bisulphid on the growth of corn and mustard in acid soils*

No.	Soil.	Carbon bisulphid added.	Weight of corn.			Weight of mustard.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
		Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami silt loam	Control.	190	50	64. 5	83	18	19. 5
2	....do	Control.	360	79		145	21	
3	....do	2	315	70	65	159	27	25. 5
4	....do	2	320	60		150	24	
5	Sparta sand	Control.	65	17	17. 5	13	2. 5	3
6	....do	Control.	70	18		19	3. 5	
7	....do	2	100	21	23. 5	11	2	2. 5
8	....do	2	120	26		12. 5	3	
9	Colby silt	Control.	......	83	84. 5	......	......	10
10	....do	Control.	393	86		67	10	
11	....do	2	390	85	81	62	9. 6	9. 6
12	....do	2	385	77		......	......	
13	Peat	Control.	160	28	24	0	......	......
14	....do	Control.	130	20		0	......	......
15	....do	2	165	25	22. 5	0	......	......
16	....do	2	......	20		0	......	......

It is clear from the data that carbon bisulphid does not materially benefit corn. An exception to this was seen in the case of Sparta sand; in this instance the treated series showed a slight improvement.

A comparison of the growth of mustard in acid and in neutral soil shows that this crop grows best in a neutral soil. In Sparta sand and Colby silt loam the yield of mustard in the treated soil was below that of the control, while in the peat soil it failed entirely. It seems very probable that the acid reaction of the soil inhibits the growth of mustard. For instance, Kossovich (7) reports that mustard is sensitive to acidity. The addition of 2 per cent of carbon bisulphid to Miami soil stimulated the growth of mustard. This agrees with the results of previous tests. An increase in the growth of mustard has been noted in all four experiments with carbon bisulphid in Miami soil.

One series of jars, corn on Miami silt loam, was replanted to buckwheat. As previously reported, buckwheat showed a distinct improvement in the carbon-bisulphid soil. If the control weights are taken as 100, the treated series is equal to 115.

A review of all the data on the effect of carbon bisulphid on higher plants shows very clearly that carbon bisulphid does not produce the same effect on all plants. In almost every case (except acid soils) the carbon bisulphid favors in a decisive way the growth of mustard. Next in order of their response to carbon bisulphid come rape, red clover, buckwheat, oats, and corn. In acid soils, especially those rich in organic matter, the growth of clover is greatly favored by the carbon-bisulphid treatment.

The majority of the evidence indicates that carbon bisulphid is most beneficial to the growth of higher plants in peat or in open, sandy soils.

EFFECT OF CARBON BISULPHID ON THE GROWTH OF PLANTS IN SILICA SAND

If carbon bisulphid is a plant stimulant, then the addition of the proper amount to a nutrient solution for plants should exert a beneficial effect on the growth of higher plants. To test this a series of experiments was performed on different plants.

BUCKWHEAT AND OATS

Eight jars were filled with pure silica sand (99 per cent pure quartz), and the following ingredients added to each jar:

Water (H_2O)	500 c.c.
Potassium nitrate (KNO_3)	5 gm.
Ferrous phosphate ($Fe_3(PO_4)_2$)	1.25 gm.
Calcium phosphate ($Ca_3(PO_4)_2$)	1.25 gm.
Calcium sulphate ($CaSO_4$)	1.25 gm.
Magnesium sulphate ($MgSO_4$)	1.25 gm.

In addition to the soluble plant food, half of the jars received 2 per cent of carbon bisulphid. After treatment the jars were held for two months before planting to buckwheat and oats. The results of the test are given in Table XIV.

TABLE XIV.—*Effect of carbon bisulphid on the growth of buckwheat and oats in silica sand*

No.	Carbon bisulphid added.	Weight of buckwheat.			Weight of oats.		
		Green.	Dry.	Average.	Green.	Dry.	Average.
	Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Control.	15.8	3.2	2.3	3.5	1.5	1.3
2	Control.	8.5	1.4		3.4	1.2	
3	2	37.5	7	5.6	....	....	6.5
4	2	21	4.2		21	6.5	

It is apparent from the data that carbon bisulphid in silica sand exerts a beneficial effect on the growth of both buckwheat and oats. This agrees with the results of Koch (6)—that carbon bisulphid stimulates the higher plant growth. Although the duplicate jars do not agree very closely, the highest yield of the control was lower than any of the treated groups. For some unexplainable reason, the oats in jar 3 failed to grow. The young seedling died soon after germination. Plate II, figure 3, is a reproduction of a photograph of the buckwheat series.

CLOVER, BUCKWHEAT, AND MUSTARD

The foregoing experiment was repeated, using 3-kgm. jars and Tollen's medium. Only 1 per cent of carbon bisulphid was added. The jars were planted 30 days after treatment. The yields of the different crops are presented in Table XV. From the beginning clover and mustard began to show the favorable effect of carbon bisulphid.

TABLE XV.—*Effect of carbon bisulphid on the growth of buckwheat, clover, and mustard in silica sand*

No.	Carbon bisulphid added.	Weight of buckwheat.			Weight of clover.			Weight of mustard.		
		Green.	Dry.	Average.	Green.	Dry.	Average.	Green.	Dry.	Average.
	Per cent.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Control.	49	7.5	7	4.5	1	1.4	77	9	9
2	Control.	41	6.6		10	1.8		.....	.....	
3	1	49	7.8	7.6	12	2.2	2.2	52	5.8	8.6
4	1	45	7.5		12	2.3		98	11.5	

As compared with the results shown in Table XIV, the increase in the growth of buckwheat with carbon bisulphid was much smaller. The clover crop was about doubled in the presence of carbon bisulphid. Mus-

tard did not do well in sand cultures; growth was very irregular. Because of the size of the jars and the irregular growth of the crops it will be necessary to repeat the experiment.

EFFECT OF CARBON BISULPHID IN REINOCULATED SOIL

In the first part of this paper it has been shown that if soil treated with carbon bisulphid is reinoculated with fresh soil the bacterial processes are altered. The increase in number of bacteria attains a maximum much sooner and begins to decline earlier than in soil treated with carbon bisulphid but not reinoculated. This is also noted in the formation of soluble nitrogen. In order to record the effect on plant growth, the following experiment was planned. Six jars with 9 kgm. each of Miami silt-loam soil were used. Two months after treatment with carbon bisulphid, 2 per cent of untreated soil were added to jars 5 and 6. An equal amount was removed before the original soil was added. All of the jars were kept for another month before planting.

Plate counts three months from the date of treatment showed a decided increase in number of bacteria in the carbon-bisulphid soils. No appreciable difference existed between the carbon bisulphid and the carbon-bisulphid reinoculated soil.

The effect of treatment on nitrate content is evident from the following figures: If the nitrate nitrogen at the beginning is 100, then the control after three months is 370, carbon bisulphid is 50, and carbon bisulphid plus 2 per cent of the original soil is 44. Here, again, the inverse relation of number of bacteria and nitrate content is noted.

Protozoa were found in all of the soils and apparently in about the same number two months after treatment as in the original soil.

The effect of this treatment on the growth of oats and corn may be seen from the figures in Table XVI.

TABLE XVI.—*Effect of carbon bisulphid on the growth of oats and corn in reinoculated soil*

No.	Soil.	Treatment.	Weight of first crop, oats.			Weight of second crop, corn.		
			Green.	Dry.	Average.	Green.	Dry.	Average.
			Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Miami.	Control	168	51	50.9	107	28	29
2	...do...	.....do	178	50.75		108	30	
3	...do...	2 per cent of carbon bisulphid.	178	50	52	86	33	29.5
4	...do...	.....do	185	54		83	26	
5	...do...	2 per cent carbon bisulphid plus 2 per cent of the original soil.	178	51.5	56.5	79	22	24
6	...do...	.....do	215	61.5		101	26	

The average dry weight of oats in soil treated with carbon bisulphid was slightly greater than that of the control. This difference was most noticeable in the case of reinoculated soil. It appears that the reinoculation benefits the action of carbon bisulphid on the growth of oats. The second crop of corn gave the opposite results. The corn in untreated soil gave the highest yield.

EFFECT OF CARBON BISULPHID ON THE ACCUMULATION OF SULPHATES IN SOIL

Very soon after the jars were planted it was observed that the surface of carbon-bisulphid soil was partly covered with needle-like crystals. Qualitative tests showed that these were made up largely of sulphates, possibly magnesium sulphate. The occurrence of salts was noted in several of the soils treated with carbon bisulphid. Possibly a part of the carbon bisulphid was oxidized to sulphates. It has been reported that a small portion of the carbon bisulphid may be converted into sulphates (4, p. 247–251; 10, p. 151–152).

Samples of the treated and untreated soils were analyzed for sulphates.[1] The results are shown in Table XVII.

TABLE XVII.—*Effect of carbon bisulphid on the accumulation of sulphates in the soil*

No.	Time.	Treatment.	Sulphur as sulphates.
	Months.		*Per cent.*
1	1	Untreated	0.023
2	1	2 per cent of carbon bisulphid	.038
3	3	Untreated	.018
4	3	2 per cent of carbon bisulphid	.039
5	5	Untreated	.019
6	5	2 per cent of carbon bisulphid	.060

It is apparent from the data in this table that the addition of carbon bisulphid tends to increase the sulphate content of the soil.

CONCLUSIONS

The addition of carbon bisulphid to soil exerts a decided effect on the fauna and flora of the soil. This is characterized by a temporary reduction in the number of micro-organisms. Later, an enormous multiplication of bacteria takes place and an almost parallel increase in production of by-products or soluble nitrogen is noted. The ammonia content seems to follow the curve of bacterial growth and later gives way to larger amounts of nitrate. From the evidence it seems that carbon bisulphid in soil produces an increase in soluble compounds of nitrogen and sulphur.

[1] The author is indebted to Prof. W. E. Tottingham, of the Department of Agricultural Chemistry, for the analyses.

In Miami soil carbon bisulphid benefited the growth of buckwheat, oats, and mustard. No relation seems to exist between plant stimulation with carbon bisulphid and the form of the soluble nitrogen. In nonacid soils carbon bisulphid is most beneficial to sulphur crops. Mustard offers a good example. In all of the experiments, except acid soils, mustard showed an increased growth from the use of carbon bisulphid. Carbon bisulphid in peat soil greatly benefits the growth of red clover. In sand cultures plus soluble plant food carbon bisulphid favors the growth of certain plants.

The data show clearly that carbon bisulphid does not act alike in all soils or toward all crops.

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PLATE I

Plate cultures of soil organisms growing on agar:

Fig. 1.—Colonies of organisms from untreated soil.

Fig. 2.—Colonies from soil treated with 2 per cent of carbon bisulphid.

Fig. 3.—Colonies from soil treated with 2 per cent of carbon bisulphid and evaporated.

Fig. 4.—Colonies from soil treated with 2 per cent of carbon bisulphid, evaporated, and reinoculated with 5 per cent of soil from an untreated jar.


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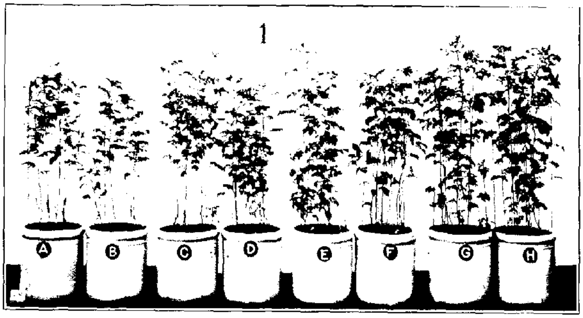
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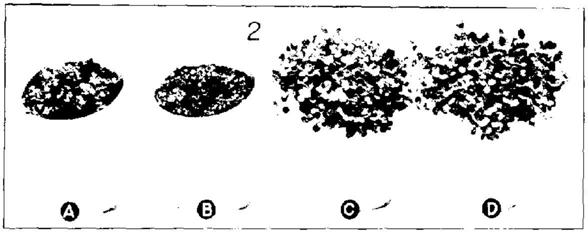
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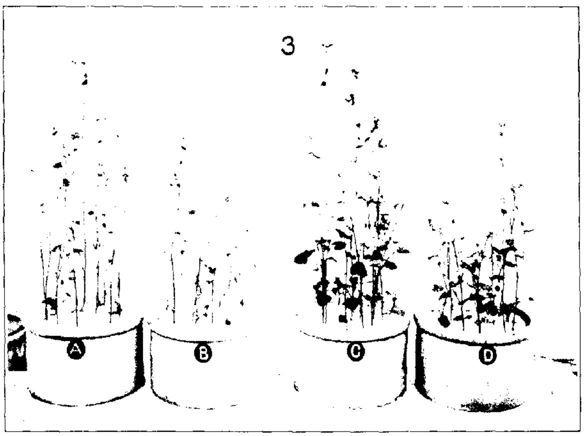
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PLATE II

Fig. 1.—Effect of varying amounts of carbon bisulphid on mustard; *A*, *B*, soil untreated; *C*, *D*, soil treated with 0.5 per cent of carbon bisulphid; *E*, *F*, soil treated with 1 per cent of carbon bisulphid; *G*, *H*, soil treated with 2 per cent of carbon bisulphid.

Fig. 2.—Effect of carbon bisulphid on clover in peat soil; *A*, *B*, soil untreated; *C*, *D*, soil treated with 2 per cent of carbon bisulphid.

Fig. 3.—Effect of carbon bisulphid on buckwheat in sand cultures; *A*, *B*, soil untreated; *C*, *D*, soil treated with 2 per cent of carbon bisulphid.

CLIMATIC CONDITIONS AS RELATED TO CERCOSPORA BETICOLA [1]

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INTRODUCTION [2]

Climatic conditions of both winter and summer bear an important relation to the vitality and development of *Cercospora beticola*. During cold weather certain conditions enable the fungus to overwinter, while certain other conditions are inimical to its growth, a fact which has an important bearing on the control of the disease, as the earliest infections on growing sugar beets (*Beta vulgaris*) originate from the overwintered fungus. In the early summer, after infection occurs, temperature, relative humidity, rainfall, and wind directly affect the development of the fungus, the rapidity of conidial production, and subsequent infection.

OVERWINTERING

From the investigations here described it seems evident that under ordinary field conditions of winter the conidia of *C. beticola* usually live but a short time, although under ordinary herbarium conditions desiccation takes place only after exposure for several months. The sclerotia-like bodies (fig. 1, *A*, *a*), or masses of mycelium, the most resistant part of the fungus, which are embedded in the infected areas of the leaf blades and petioles, however, live over the winter under favorable conditions and in the spring produce conidia from the remnants of the old conidiophores (fig. 1, *A*, *b*), or both conidiophores and conidia (fig. 1, *A*, *c*) may be formed anew. For the purpose of making direct microscopical observation of such development sections of infected tissue which had been stored throughout the winter under favorable conditions were placed in hanging-drop cultures of bean agar. New conidiophores (fig. 1, *B*, *b*) grew from the masses of embedded mycelium, and although somewhat abnormal they produced rather typical conidia (fig. 1, *B*, *c*), thus showing that such material may be a source of early infection of growing plants.

[1] The investigations were carried on entirely in the field. Preliminary work was conducted during 1911 and 1912 at Rocky Ford, Colo. The detailed data were collected during 1912 and 1913 at Rocky Ford, which is in the Arkansas Valley of Colorado, a semiarid region under irrigation, and during 1914 near Madison, Wis., where the rainfall and average humidity were greater.

[2] The writers are indebted to Mrs. Nellie E. Fealy, of the Bureau of Plant Industry, for aid in editing and revising the manuscript.

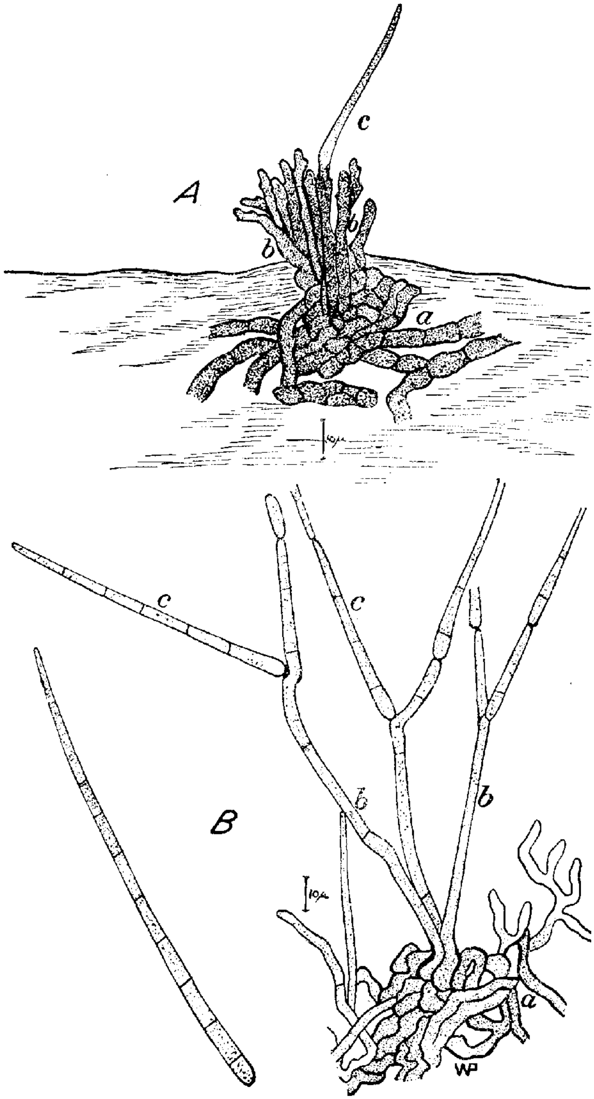

FIG. 1.—*Cercospora beticola*: *A*, Section of overwintered sugar-beet leaf showing embedded sclerotia-like body, *a*, with a mass of old conidiophores, *b*, from which a new conidium, *c*, was produced. *B*, Production of rather typical conidiophores, *b*, and conidia, *c*, from a sclerotia-like mass, *a*, taken from over-

CONIDIA

Thümen (1886, p. 50–54)[1] believed that the spores of *Cercospora beticola* are able to live for a certain length of time in the soil and retain their viability and produce new infection, and Pammel (1891, p. 238–243) and Massee (1906, p. 52–53) accord with this view. In the investigations here considered it was found that when kept dry, as in the case of herbarium material, the conidia remained viable for 8 months (Table I, tests 10 to 13), but soon after that no growth occurred. Only rarely were conidia found on the infected areas of the leaves which were exposed to outdoor weather conditions, and such conidia seemed to lose their vitality soon after harvest. No germination was found to take place under optimum conditions in the case of conidia which had been thus exposed from 1 to 4 months (tests 14 and 15). However, conidia occasionally found on spots that had been well protected, for instance in the interior of a pile of hayed beet tops, retained their viability for from 5 to less than 12 months (tests 16 and 17). Since the conidia are rarely found after a short time even on infected material that has been well protected and since they rarely germinate after being exposed outdoors for even 1 month after harvest, it would seem that under ordinary field conditions they play no important part in the overwintering of the fungus.

TABLE I.—*Viability of the conidia of Cercospora beticola as affected by desiccation*

Test No.	Environment.	Period of exposure.	Viability.
1	Stored, dry	14 years	None.
2	....do	11 years	Do.
3	....do	10 years	Do.
4	....do	5 years	Do.
5	....do	4 years	Do.
6	....do	3 years	Do.
7	....do	2 years	Do.
8	....do	11 months	Do.
9	....do	10 months	Do.
10	....do	8 months	Slightly viable.
11	....do	7 months	Extremely viable.
12	....do	6 months	Do.
13	....do	5 months	Do.
14	Left in field after harvest, Colorado	1 month	None.
15	Left in field after harvest, Wisconsin	4 months	Do.
16	Stored inside pile of hayed sugar-beet leaves	5 months	Extremely viable.
17	....do	12 months	None.

SCLEROTIA AND MYCELIUM

Various investigators have attempted to determine whether different fungi live in the soil over winter and the manner in which they overwinter. Treboux (1914) found that the mycelia of several different rusts overwinter on host material freely exposed to climatic conditions. Stewart (1913) placed in boxes of soil potato leaves and tubers infected with *Phytophthora infestans*, exposed them to outdoor winter conditions, and found that plants grown on such soil developed no blight. However,

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 60.

temperature and moisture conditions in boxes of soil exposed aboveground to winter conditions are much more varied than in soil at different depths in the field where normal overwintering usually occurs.

In the overwintering experiments here described the host material was kept in an environment comparable to ordinary field conditions. The experiments at Rocky Ford, Colo., were started about the middle of October, 1912, and continued for 11 months. In these experiments some of the infected material was mixed with soil, placed in boxes, and exposed aboveground during the winter (Pl. III, 1); a second portion was buried from 1 to 8 inches in the ground (Pl. III, 2), wire netting being used above and below the infected material to insure ready location when examinations were made for cultural tests (Pool and McKay, 1915); a third portion of the infected tops was placed in a pile on top of the ground (Pl. III, 3). During the experiment records were kept of soil and air temperatures, the former being taken at a depth of 5 inches and the latter being obtained from the Weather Bureau station at Rocky Ford.[1]

The experiments carried on near Madison, Wis., were started the last of November, 1913, and continued through the winter. Infected sugar-beet tops were buried in the soil at depths of 5 and 8 inches, while seed-beet stalks were left under ordinary conditions in the field. In this experiment also records were kept of soil and air temperatures, the former being taken from March until June at a depth of 5 inches and the latter obtained from the Weather Bureau station at Madison.

The effect of desiccation on material kept under herbarium conditions was to kill probably all life of the fungus within 12 months, as already shown, but material kept under an environment having more or less moisture accompanied by the disintegrating action of various organisms was affected in an entirely different manner, as will be shown. All cultures from the infected material used in the two experiments above outlined were made from definite leaf-spots. Although the diseased tissue was the last to be completely disorganized and consequently could be found as long as any portion of the leaf remained, it became more and more difficult to obtain such tissue as time went on.

The fungus was unable to survive six months' outdoor exposure in boxes of soil (Table II, experiment 2), and this was also true of the fungus on leaves which had been freely exposed to outdoor conditions—for instance, on the outside of a hayed pile of sugar-beet tops (experiment 3), and on leaves buried 6, 7, and 8 inches in the ground (experiments 19 to 23). In cultures from infected mother-beet stalks and leaves that had been left in the field for a time and then plowed under or stored there was no growth, or only an indefinite growth, of the fungus after 7 months (experiments 8 to 10), while in infected material that had been protected in the interior of a pile of hayed beet tops (experiment 4) and in material

[1] All the records included in this paper from the Weather Bureau station at Rocky Ford, Colo., were kindly furnished by Mr. P. K. Blinn, the local observer.

that had been slightly covered or buried from 1 to 5 inches in the ground the life of the fungus was entirely extinct after 12 months (experiments 11 to 18). The death of the fungus in material plowed under is due in all probability to the rapid disorganization which results under favorable temperature and moisture conditions, such, for instance, as those which prevailed at Rocky Ford through the winter of 1912–13. During that period there was insufficient moisture to permit severe freezing, but there was a daily extreme variation of soil temperature, indicating that the air temperature produced the changes through the more or less dry soil. In the experiments at Madison there was only a partial disintegration of the buried beet tops six months after harvest, but other factors impaired the vitality of the fungus and its life appeared to be entirely extinct; consequently, notwithstanding the great differences in soil factors, comparable results as to the life of the fungus were obtained from the experiments at both places.

TABLE II.—*Effect of desiccation and overwintering on the viability of Cercospora beticola in infected sugar-beet tops under field conditions at Rocky Ford, Colo., and Madison, Wis.*

Experiment No.	Environment of sugar-beet-top material.	Period of exposure.	Number of spots from which cultures were made.	Number of viable spots.	Condition of leaves.
[a] 1	Dried, stored:				
	Illinois, Iowa	14 years	10	0	Good.
	Connecticut	11 years	10	0	Do.
	New York	10 years	10	0	Do.
	Wisconsin	5 years	10	0	Do.
	Iowa	4 years	10	0	Do.
	Maryland	3 years	10	0	Do.
	Colorado	2 years	10	0	Do.
	New Jersey	10 months	10	3	Do.
	Colorado	9 to 11 months	20	10	Do.
2	Stored in soil in boxes and left free under outdoor conditions, Colorado.	2 months	15	15	Do.
		3 months	7	7	Do.
		4 months	13	4	Do.
		5 months	12	2	Do.
		5½ months	12	0	Do.
		7 months	6	0	Do.
3	From the outside of "hayed" pile of sugar-beet tops, Colorado.	7 months	6	0	Do.
		10 months	13	0	Do.
4	From the interior of "hayed" pile of sugar-beet tops, Colorado.	2 months	10	10	Do.
		3 months	66	64	Do.
		4 months	29	27	Do.
		5 months	40	40	Do.
		7 months	18	12	Do.
		10 months	15	10	Do.
		12 months	25	0	Do.
5	In field, Colorado	2 months	10	10	Do.
		5 months	11	8	Do.
		8 months	10	2	Do.
6	Leaves from "mother beet" stalks free in field, Wisconsin.	5 months	21	15	Do.
7	First-year sugar-beet leaves free in field, Wisconsin.	5 months	32	3	Do.
		8 months	40	0	Partially disintegrated.
8	Spots on "mother beet" stalks free in field, Wisconsin.	4 months	7	[b] 7	Good.
		7 months	35	4?	Do.
9	Spots on "mother beet" stalks free in field 6 months, then plowed under 1 month, Wisconsin.	7 months	10	0	Somewhat softened.

[a] Herbarium specimens for this test were furnished by Barrett, Illinois; Clinton, Connecticut; Whetzel, New York; Pammel, Iowa; Norton, Maryland; and Cook, New Jersey.
[b] 395 colonies.

TABLE II.—*Effect of desiccation and overwintering on the viability of Cercospora beticola in infected sugar-beet tops under field conditions at Rocky Ford, Colo., and Madison, Wis.*—Continued

Experiment No.	Environment of beet-top material.	Period of exposure.	Number of spots from which cultures were made.	Number of viable spots.	Condition of leaves.
10	Spots on "mother beet" stalks free in field 4 months, then stored dry 3 months, Wisconsin.	7 months..	10	5?	Good.
11	Buried 1 inch in ground, Colorado....	6 months..	21	0	Partially disintegrated.
		7 months..	10	2	Do.
		10 months.	8	3	Greatly disintegrated.
		12 months.	24	0	Entirely disintegrated.
12	Buried 2 inches in ground, Colorado..	5 months..	14	2	Partially disintegrated.
		6 months..	19	10	Do.
		10 months.	11	0	Greatly disintegrated.
		12 months.	28	0	Entirely disintegrated.
13	Buried 3 inches in ground, Colorado..	6 months..	21	10	Partially disintegrated.
		10 months.	11	1	Greatly disintegrated.
		12 months.	18	0	Entirely disintegrated.
14	Broken and buried 3 inches in ground, Colorado.	6 months..	14	0	Greatly disintegrated.
		7 months..	12	5	Do.
		10 months.	16	0	Entirely disintegrated.
15	Buried 4 inches in ground, Colorado..	6 months..	19	5	Partially disintegrated.
		10 months.	19	1	Greatly disintegrated.
16	Buried 5 inches in ground, Colorado..	6 months..	20	4	Do.
		10 months.	15	0	Entirely disintegrated.
		12 months.	20	0	Do.
17	Buried 5 inches in ground, Wisconsin.	4 months..	30	0	Good.
		5 months..	30	3?	Do.
		6 months..	81	0	Do.
		7 months..	80	0	Partially disintegrated.
18	Plowed under in field, about 5 inches, Wisconsin.	5 months..	30	3?	Do.
		5 months..	20	0	Do.
19	Buried 6 inches in ground, Colorado..	5 months..	8	0	Greatly disintegrated.
		6 months..	20	4	Do.
		10 months.	12	0	Do.
		12 months.	15	0	Do.
20	Broken and buried 6 inches in ground, Colorado.	6 months..	18	0	Do.
		7 months..	10	0	Do.
		10 months.	16	0	Entirely disintegrated.
21	Buried 7 inches in ground, Colorado..	6 months..	15	0	Do.
		7 months..	10	0	Do.
		10 months.	12	0	Do
		12 months.	22	0	Do
22	Buried 8 inches in ground, Colorado..	6 months..	20	0	Do
		7 months..	10	0	Do.
		10 months.	12	0	Do.
23	Buried 8 inches in ground, Wisconsin.	4 months..	30	0	Good; ground frozen.
		5 months..	35	2?	Good.
		6 months..	57	0	Good; leaves have sour odor.
		6½ months	100	0	Partially disintegrated.

These experiments and observations made in the field during several spring and summer months showed that on leaves slightly protected on or near the surface of the ground during the winter *C. beticola* can live a sufficient length of time to be a source of infection for the succeeding sugar-beet crop and that the fungus is entirely killed by planting time when the infected material is plowed under to a depth of 6 to 8 inches in the fall.

AIR AND SOIL TEMPERATURES AT ROCKY FORD, COLO., AND AT MADISON, WIS.

Comparison of the air and soil temperatures which prevailed during the experiment at Rocky Ford and Madison showed a wide difference.

One of the most striking characteristics of these temperatures at Rocky Ford was the wide range between the maximum and the minimum, and this range may be observed throughout the entire records (fig. 2, 3). In the case of the soil temperatures especially, the wide range appeared to be due to a lack of moisture, the extreme variations being greater than if more moisture had been present. A comparison of the records shows that the variation in air temperature was much less and the mean daily temperature constantly lower at Madison than at Rocky Ford, notwithstanding the fact that the daily minimum temperature was usually lower at Rocky Ford. A comparison of the soil temperatures at the two points, however, shows that at Madison it probably remained more constant and was never as low as at Rocky Ford. This was due apparently to the greater amount of moisture in the soil at Madison and consequently its continued frozen condition. After March 23, the date on which the record was begun at Madison, the soil temperature at that place was never below 29° F., notwithstanding the fact that the air temperature was as low as 15° on April 8, while the minimum soil temperature at Rocky Ford was 22° on December 21 and 25° on February 8. However, as the air temperature on these dates was lower here than at Madison, comparisons can not be drawn too closely.

In view of the presence of snow on the ground, which, as is well known, protects the soil from the extreme variations of air temperature, and the prevailing low air temperatures, as shown by the records, it may be assumed that the soil temperatures at Madison during January and February and the early part of March varied but little from freezing. This assumption is supported by Frödin's experiments (1913), which showed in general that when the air temperature was much lower than that of the soil the soil temperature in ground covered with snow was higher than in bare ground. He found that temperatures taken at a depth of 10 cm. in the former were the same as those taken at a depth of 27.4 cm. in the latter. After the early part of April the minimum soil temperatures at Rocky Ford and Madison agreed closely, although the minimum air temperature at the former place remained generally the lowest of the temperatures recorded.

Temperatures obtained from the interior of a pile of hayed sugar-beet leaves by means of a soil thermograph buried in the pile varied less than temperatures taken outside the pile, as shown by the following records made on May 8, 1913, and as was probably the case during the entire winter season: Temperature inside pile, maximum, 67° F.; minimum, 58°; difference, 9°. Temperature outside pile, maximum, 84° F.; minimum, 45°; difference, 39°.

In view of the fact that the fungus lived twice as long inside the pile as it did on the outside it would seem that a more uniform temperature might be regarded as one of the controlling factors in the life of the fungus.

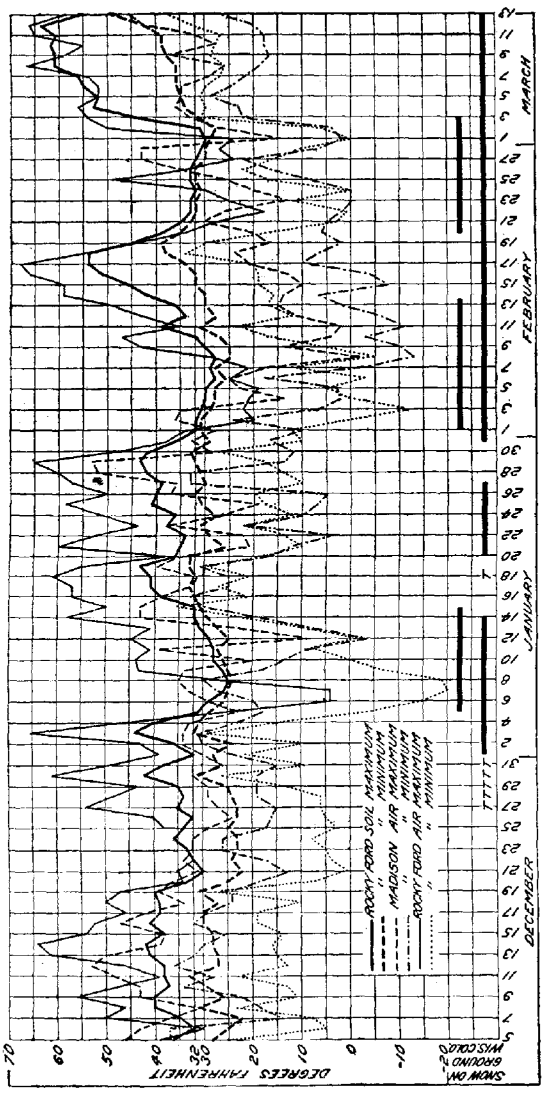

FIG. 2.—Curves of the maximum and minimum soil and air temperatures for the period from December 5, 1912, to March 13, 1913, at Rocky Ford, Colo., and air temperatures from December 5, 1913, to March 13, 1914, at Madison, Wis., together with the periods that snow covered the ground.

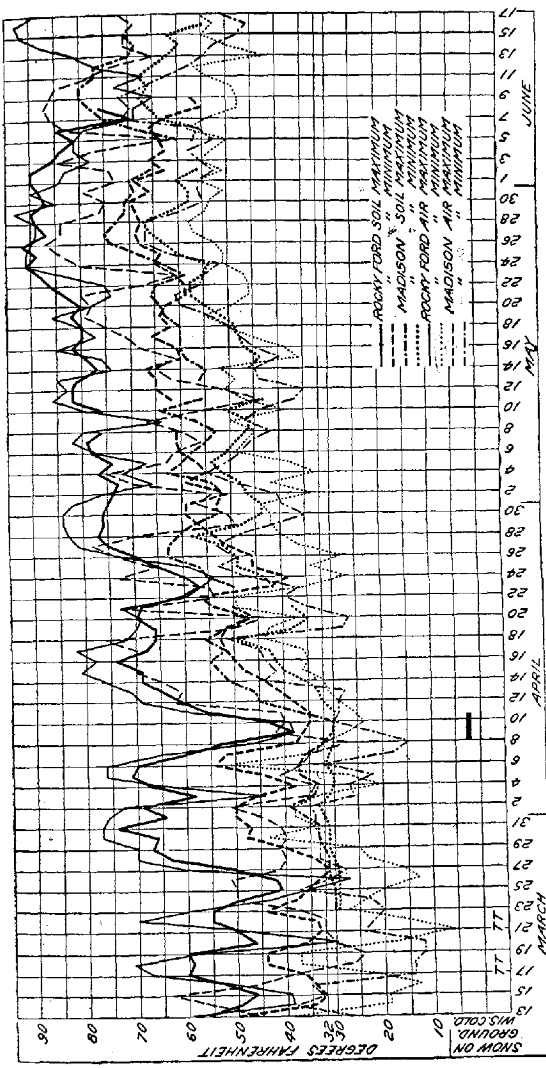

FIG. 3.—Curves of the maximum and minimum soil and air temperatures for Rocky Ford, Colo., from March 13 to June 17, 1913, and for Madison, Wis., from March 13 to June 17 1914

Low temperatures are not entirely inhibitive, as was shown by thermal tests of artificial cultures. After such cultures had been exposed to temperatures averaging 0.9° C. for 48 days and then kept at 28° C., numerous colonies developed. Also, heavily infected leaves kept at 0.9° C. for 97 days yielded good growth when cultures were made and held at favorable temperatures. Had the cultures been exposed to freezing temperatures or to extreme variations in temperature, the effect would doubtless have been more pronounced.

Although the temperature variations and the amount of soil moisture at Rocky Ford and Madison differed greatly, the effect on the life of the fungus was apparently the same at both places. It may be concluded that conditions of the soil which favor the process of disintegration are the most important factors in the control of the disease, and these experiments indicate that these processes are most active at a depth of 6 to 8 inches.

SUMMER CLIMATIC CONDITIONS

The summer climatic conditions here considered were recorded during 1913 in fields of first-year sugar beets grown at Rocky Ford, these fields being an example of the usual progress of the disease where neither rotation nor sanitation at the preceding harvest time had been practiced.

A study of the temperature and humidity records taken at different places in a beet field at Rocky Ford and at the Weather Bureau station 3 miles from the field was made to determine their comparative values in making important correlations. The records made in the sugar-beet field were taken by means of hydrothermographs kept in meteorological instrument shelters 5 feet above the ground (Pl. IV, fig. 1) and among the plants (Pl. IV, fig. 2). These were checked at frequent intervals with a sling and cog psychrometer (Shaw, 1914), respectively, and under Colorado conditions were found to be accurate. The records of the Weather Bureau station were taken by means of maximum and minimum thermometers kept in an instrument case about 5 feet above the ground in an open space (fig. 3).

The daily maximum and minimum temperatures and humidities, together with the total number of hours the humidity was above 60 from noon of the preceding day to noon of the given day, are used in the present interpretations. It has been found that when a high relative humidity prevails, the stomata of the sugar-beet leaves are usually open; and as the fungus enters the leaves only through the open stomata, the length of time they remain open is a fundamental factor in determining the possible occurrence of infection (Pool and McKay, 1916).

AIR TEMPERATURE AND RELATIVE HUMIDITY

The temperature and relative humidity taken with hygrothermographs placed near the ground among the plants varied widely from those taken with hygrothermographs in the air above the field and also from those

taken at the Weather Bureau station; hence, the place where the records were taken for use in the present correlations with the development of the disease is an important consideration.

AIR TEMPERATURE.—At Rocky Ford the maximum temperatures taken among the plants near the surface of the ground from June 13 to 30 ranged from 2 to 19 degrees higher and the minimum temperatures generally from 1 to 14 degrees lower than those taken at 5 feet above the ground (fig. 4). This was due to the fact that the plants were small during this period and covered only a portion of the ground; consequently during the daytime the temperature of the soil became higher than that of the air, and in turn the temperature of the air near the ground became higher than that of the air a few feet above. During the night the reverse occurred, the surface soil losing its heat by radiation and conduction faster and finally reaching a lower temperature than that of the air in contact with it, after which the heat of the latter gradually passed into the soil and as a result the temperature of the air immediately above the ground eventually became lower than that a few feet higher up. It is possible that convection currents also tended to lower the temperature of the air immediately above the ground; for, as is well known, when it is not disturbed by other factors, the coolest air settles to the lowest levels.

The maximum temperatures of the air near the ground, as shown by the records, were higher for a longer period during June than at any time during the season, varying from 100° to 106° F. on nine different days between the 14th and 26th of that month and rising above 100° only once thereafter, on August 16. The maximum temperature of the air 5 feet above the ground, on the other hand, was lower during June than during the middle of the season, ranging from 90° to 93° on six different days during the month, while it was above 90° and sometimes as high as 100° on 12 different days during July.

As shown by the records, the temperature of the air near the ground among the plants was lower during the middle than during the early part of the season. This was probably due to the difference in the size of the plants, the larger plants practically covering the ground in midseason and preventing the heating of the surface soil, while early in the season the smaller plants covered the ground but sparsely and consequently afforded less protection against heating. Comparison of the records also shows that during the middle of the season the temperature of the air among the plants near the ground was practically the same as that of the air 5 feet above the field and that throughout the entire period the latter was quite comparable with the temperatures taken at the Weather Bureau station (fig. 4).

A similar marked variation was shown at Madison, the maximum temperature there being almost constantly higher and the minimum tempera-

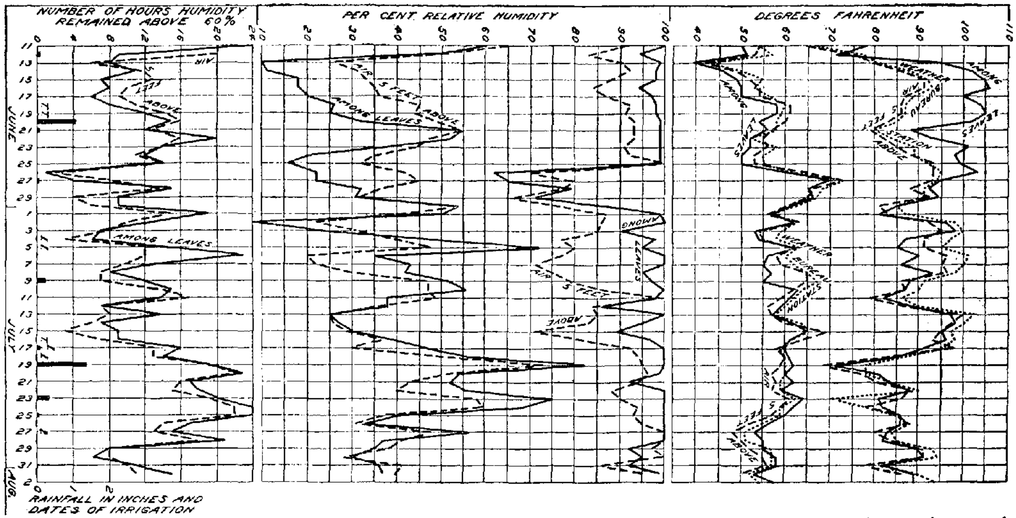

FIG. 4.—Curves of the maximum and minimum temperatures and relative humidities and the number of hours that the humidity remained above 60 from noon of the preceding to noon of the given day among sugar-beet plants *and in the air 5 feet above* the field, together with the field rainfall and irrigation records. For comparison, the maximum and minimum temperature records from the Weather Bureau station are included. June 11 to August 2, 1913, at Rocky Ford, Colo.

ture usually lower among the beet plants than the temperature shown by the Weather Bureau records, which were taken on top of a four-story building about a mile from the sugar-beet field. These wide variations between the air temperature taken near the ground among the plants and that taken 5 feet above the field and between the former and the temperature taken at the Weather Bureau stations show that for correlation with fungous activities only the records taken among the plants should be used.

RELATIVE HUMIDITY.—There was also a wide variation in the humidity near the ground among the plants and 5 feet above the field. For instance, the daily minimum humidity at Rocky Ford from June 13 to 29, with two exceptions, was higher and remained above 60 generally for a longer period in the air above the plants than among the leaves near the ground (fig. 4), owing to the higher temperature at the surface of the ground as a result of the small amount of covering afforded by the young plants. During this period the daily variation of humidity among the leaves was extreme, ranging from 99 to 10 on June 13, from 99 to 16 on June 25, and from 100 to 8 on July 2. After June 29, on the other hand, the minimum humidity was generally higher, the humidity remained above 60 for a longer time among the leaves than in the air above, and the daily variation among the leaves was less extreme than earlier in the season. These conditions were due mainly to the greater amount of covering afforded by the larger plants and consequent longer retention of moisture among the leaves. The humidity both among the plants and in the air 5 feet above the field remained, on an average, above 60 for a longer time each day during midsummer than during June, owing in part to the increased use of irrigation water as the season advanced and the increased amount of moisture in the surrounding air resulting from the increased transpiration of the larger plants.

Comparison of the Madison and the Rocky Ford records (fig. 5) of the number of hours that the relative humidity remained above 60 each day among the sugar-beet plants shows that throughout the season it was higher, on an average, at Madison. Here it remained above 60 for a longer time each day during the latter half of June, when the records were started, and for a shorter time each day during August than during any other summer month. This was due to difference in the amount of rainfall, there being frequent rains during the former period and comparatively dry weather during the latter. At Rocky Ford the facts were reversed, the humidity remaining above 60 for a longer time each day during midseason than during the latter half of June or the first part of September. This was probably due to more frequent irrigation and the increased covering afforded by the larger plants of midseason.

Table III shows the average number of hours a day that the relative humidity remained above 60 at Madison and at Rocky Ford.

TABLE III.—*Average number of hours a day that the relative humidity was above 60 at Madison, Wis., and Rocky Ford, Colo., during the summer of 1914 and 1913, respectively*

Date.	Madison, Wis. (1914).	Rocky Ford, Colo. (1913).
	Hours.	*Hours.*
June 16 to 30	19.4	10.8
July	17.3	14.2
August	16.6	14.1
September 1 to 6	18.0	11.3
Seasonal average	17.4	13.4

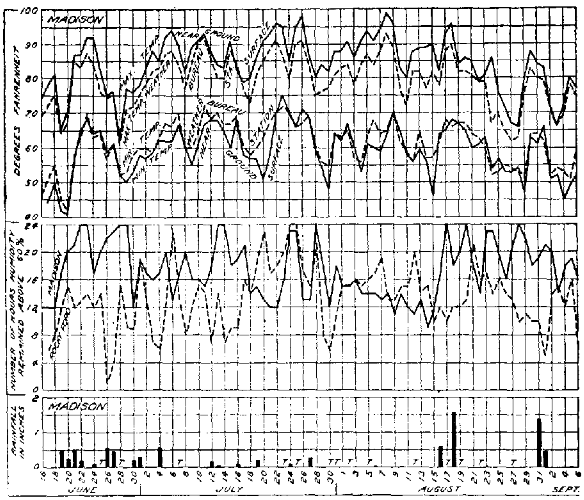

FIG. 5.—Curves of the maximum and minimum temperatures among sugar-beet plants and at the Weather Bureau station, and the seasonal rainfall records at Madison, Wis., in 1914, and the number of hours that the humidity remained above 60 among the sugar-beet plants in the field at Madison, Wis., in 1914, and at Rocky Ford, Colo., in 1913.

The greater average number of hours of high humidity at Madison accounts for the periods of extreme infection which occurred there when the fungus was present. Here leaves badly infected with *Cercospora beticola* and entirely covered with conidia were found at times, but this condition was rarely seen at Rocky Ford. There were numerous cases of cotyledon infections also at Madison, the high humidity early in the season favoring their occurrence; but no such infections were found at Rocky Ford.

RAINFALL AND IRRIGATION

The rainfall records made during the summer season of 1913 in the beet field at Rocky Ford in which infection was studied in detail (fig. 4, 7) where obtained by means of a rain gauge placed at the edge of the sugar-beet field (Pl. IV, fig. 1). Most of the rain was in the form of local showers, the amount varying greatly within a radius of less than 2 miles; but occasionally general rains fell. The effect of the increased relative humidity resulting from rainfall usually lasted longer among the leaves than in the air 5 feet above (fig. 7).

The effect of irrigation on humidity was found to be similar to the effect of rain. On July 2, before the field was irrigated, its humidity was as low as 8 and on July 3 and 4 remained above 60 for 7 and 6 hours, respectively. On July 4 and 5 the field was irrigated and the humidity remained above 72 on the 4th and above 60 during 23 hours of the 5th. On July 27 the field was again irrigated and the humidity remained above 60 for 15 hours that day and 21 hours the following day. On August 19 and 20 the field was irrigated the third time and the humidity remained above 60 for 12 and 13 hours, respectively, and the next day 21 hours. The general humid conditions necessary for leafspot infection, however, are developed much better by rain than by irrigation, because of the latter being comparatively local and unaccompanied by the atmospheric conditions attending rainfall.

WIND

Records of wind velocity at Rocky Ford were taken by means of an anemometer placed 6 feet in the air at the edge of the beet field (Pl. IV, fig. 1), the readings being made at irregular intervals and the velocities computed being the hourly averages from one reading to the next. As the records were not made daily, accurate hourly velocities for different intervals during the day can not be obtained from the records. They show, however, that the average seasonal velocity from June 12 to September 22 was 5.3 miles per hour. Occasionally two daily readings were made, one in the morning and the second late in the afternoon. These show that the average velocity of the wind was always higher during the day than at night, the greatest velocity usually prevailing in the afternoon during the period of lowest humidity. While no general dissemination of conidia was correlated with high wind velocity, the afternoon combination of highest wind with lowest humidity apparently favored the dissemination of conidia. In fact, in the case of air cultures made at different times during several days, it was found that the fungus grew usually only on those exposed during the afternoon.

SUMMER INFECTION CYCLES

The thermal relations of the fungus are closely linked with the effect of various climatic factors on the production and dissemination of conidia and on infection cycles. With a view to determining these relations the fungus was grown in Petri-dish cultures in thermostats at different and varied temperatures. At first the moisture was probably more or less constant, but as time went on it became relatively low. The effect of different temperatures, however, was comparable with that observed under existing field conditions.

THERMAL RELATIONS OF THE FUNGUS IN CULTURES

Tests of the fungus on string-bean agar were made at Washington during November and December, 1913, and January, 1914. The cultures were obtained from isolations made at the time of the tests from infected sugar-beet leaves collected at Rocky Ford during the preceding September. One colony of the first isolations was macerated in 10 c. c. of sterile water, and one platinum loop of this suspension was used for each tube of medium. Three poured plates were used for each single test. The cultures were exposed to different constant temperatures and to varied constant temperatures (high and low changed to low and high, respectively). Exposures were also made for 8 hours at the higher temperatures and then for 16 hours at lower temperatures, and, after a short interval of exposure in a certain number of these tests, both temperatures were lowered, it being possible in this way to approximate night and day temperatures in the field under normal conditions.

SERIES A (DIFFERENT CONSTANT TEMPERATURES).—When the cultures were held at different constant temperatures, the abundance and size of the individual colonies gradually increased, while the time necessary for development decreased with the temperatures 12.5°, 17.3°, 19.2°, 20°, and 30.8° C. The best growth was made at a temperature of 30.8°, but this in all probability was slightly above the optimum constant temperature, as no growth took place in cultures held for 9 days at 34.7°, 35.8°, and 40.6°, respectively (Table III, series A).

SERIES B (VARIED CONSTANT TEMPERATURES).—Although no growth of the fungus took place in cultures held at constant temperatures of 34.7° and 35.5° C., a small percentage of normal colonies developed in cultures exposed for three days to these temperatures and then for several days to a temperature of 30.8°, while in cultures exposed for three days to 40.5° no growth occurred when subsequently held at 30.8°. On the other hand, in cultures exposed for three days to a temperature of 30.8° there was almost a normal development of the colonies for three days after they were exposed to 34.7°, but at the end of five days the inhibitive effect of the latter temperature became manifest. In the case of cultures

changed from 30.8° to 40.5° only a very slight increase in growth was apparent during the first three days at the higher temperature, and after that it ceased entirely (Table III, series B).

TABLE III.—*Comparative diameter of colony growth (in millimeters) of Cercospora beticola at different constant temperatures,*[a] *at decreasing and increasing constant temperatures, and at daily varied temperatures*

SERIES A, CONSTANT TEMPERATURES

	Diameter of colony growth at temperature (°C.) of—										
Maximum	2.1	7.9	11.1	14.4	19.1	20.2	21.0	33.0	36.2	37.4	41.0
Minimum	0.3	4.0	8.0	11.5	16.3	18.6	19.5	29.7	33.8	34.5	40.0
Average	0.9	5.4	8.9	12.5	17.3	19.2	20.0	30.8	34.7	35.8	40.6
Period of growth:											
3 days	0	0	0	0	0.25	0.65	0.67	3.6	0	0	0
6 days	0	0	0	.25	.8	2.2	2.3	6.4	0	0	0
9 days	0	0	.25	.6	1.5	5	4.6	7	[b] 0	[b] 0	[b] 0
11 days	0	0	.4	.85	2.8	7	6.4				
14 days	0	0	.5	1.5	4.2						
18 days	0	0	.7	2.2							
22 days	0	0	1.2	3							

[a] The temperatures of each thermostat for all tests were averaged from two daily readings continued throughout the time of the experiment.
[b] No growth occurred in these plates when held at 28° C. for 10 days.

SERIES B, DECREASING AND INCREASING CONSTANT TEMPERATURES.

	Diameter of colony growth at temperature (°C.) of—				
	[a] 34.7	[a] 35.5	[a] 40.5	[b] 30.8	[c] 30.8
Period of growth:					
3 days	0	0	0	3.6	3.4
6 days	4	3.6	0	6	3.7
8 days	[d] 8.3	[e] 9.3	0	6.4	3.7

[a] Temperature changed to 30.8° C. after three days.
[b] Temperature changed to 34.7° C. after three days.
[c] Temperature changed to 40.5° C. after three days.
[d] Only 19.2 per cent of the normal number of colonies developed.
[e] Only 12.8 per cent of the normal number of colonies developed.

SERIES C, DAILY VARIED TEMPERATURES

	Diameter of colony growth at temperature (°C.) of—						
16 hours at	14.5	14.5	14.5	20	20	20	20
8 hours at	19.2	21.6	28	30.8	34.7	35.8	40.6
Period of growth:							
3 days	0.4	0.5	0.7	1.7	0.6	0.6	0
5 days	.7	1.9	3.4	6	3.6	3.2	0
7 days	2.7	3.6	5.2	8.8	4.8	5.4	0
9 days							0

SERIES C (DAILY VARIED TEMPERATURES).—In these tests the temperatures were made to correspond closely with summer outdoor temperatures of night and day by holding the cultures for 16 hours at the lower and for 8 hours at the higher. After seven days' exposure the growth of colonies

on cultures exposed to temperatures of 14.5° and 19.2° C. averaged 2.7 mm. in diameter; after exposure for the same length of time to 14.5° and 21.6°, 14.5° and 28°, and 14.5° and 30.8° the growth gradually increased until it reached a maximum diameter of 8.8 mm; but when exposed to higher temperatures (20° and 34.7° or 20° and 35.8°) the growth gradually diminished until finally it equaled approximately that attained under 14.5° and 28°. There was no growth on cultures exposed for nine days or longer to 20° and 40.6° (Table III, series C).

SERIES D (HIGH VARIED CHANGED TO LOW VARIED TEMPERATURES).—A plate culture exposed for three days to temperatures of 20° and 40.5° C., being held 16 hours at the lower and 8 hours at the higher, and then for six days at 20° and 30.6°, developed 23 colonies, averaging 10.3 mm. by the end of the latter period, while a check plate exposed constantly to a temperature of 30.6° developed 100 colonies by the end of the latter period. A plate exposed to the higher temperatures—20° and 40.5°—for five days and then held at 20° and 30.6° for six days developed six colonies at the end of the latter period, while a plate exposed to 20° and 40.5° and then held at 20° and 30.6° for seven days developed no growth of the fungus.

Later on in this paper the fact that high minimum and maximum temperatures inhibit the growth of the fungus, as brought out by these tests, is correlated with the effect of existing high field temperatures, with their consequent accompanying factors, on the leaf spot. Although the optimum temperature variations—20° and 30.8° C.—were found to be very favorable to the development of leafspot in the field, little or no increase in the disease was observed to follow high night and day field temperatures—20° and 40.5°, respectively.

It was also observed that different temperatures affect conidial septation. The normal average septation varies from 6 to 11, but during warm, humid periods the conidia were usually found to be many septate, sometimes as high as 20-septate, while after a cooler period, such as usually occurs in September, they were only from 2- to 4-septate.

RELATION OF CONIDIAL PRODUCTION AND DISSEMINATION TO CLIMATIC CONDITIONS

For the purpose of studying the relation of temperature and relative humidity to the production and dissemination of conidia, detailed life histories of a large number of individual spots on 10 plants in the medium-early field at Rocky Ford were kept during the season of 1913. The temperature and humidity records used in these correlations were those taken among the beet leaves near the ground and, together with rainfall and dates of irrigation, are shown in figure 7.

Beginning with the outermost or oldest, the leaves were tagged and numbered consecutively, and the location of the spots on each was indi-

cated on diagrams. As new leaves developed, they were included in the observations, and this was true also of new spots, until they became too numerous, after which only a few representative ones on each leaf were studied in detail. During the period from the 24th of June to the 19th of September 330 spots were studied, both surfaces being examined at frequent intervals with a hand lens. For the purpose of getting a basis for comparison of rates of development at different stages in the life history of the disease, percentage values were assigned to each stage as follows, the spots being grouped and averaged later (Table IV):

Percentage value.	Stage of development of fungus.
5.0	Spot first noticed. Neither conidia nor conidiophores present.
12.5	Conidiophores present.
19.7	Very few conidia.
25	Few conidia.
31.2	Conidia fairly numerous.
37.5	Conidia numerous.
43.7	Conidia fairly abundant.
50	Conidia abundant.

The value of the spot is the sum of the values of the two sides—that is the value of a spot on which there were but few conidia (25) on one side, and abundant conidia (50) on the other, is 75. Again, the value of a spot on which conidiophores only (12.5) were present on one side, and very few conidia (19.7) on the other, is 32.[a]

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*[b]

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
**2	3	5	July 7	10	No conidiophores on either surface. July 8, no change.
			10	37	Conidiophores above, conidia few below.
			12	50	Conidia few on both surfaces. July 14, no change.
			16	50	Conidia very few above, fairly numerous below.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	62	Conidia fairly numerous on both surfaces.
			28	37	Conidia none above and few below.
2	4	1	2	10	No conidiophores on either surface. July 7, no change.
			8	24	Conidiophores on both surfaces.
			10	69	Conidia very few above and abundant below.
			12	75	Conidia few above and abundant below.
			14	100	Conidia abundant on both surfaces. July 16, 21, 23 (leaf yellow). July 25, no change.
			28	63	Conidia numerous above and few below.
2	4	3	7	10	No conidiophores on either surface. July 8, no change.
			10	25	Conidiophores on both surfaces.
			12	62	Conidia fairly numerous on both surfaces.
			14	82	Conidia numerous above and fairly abundant below.
			21	100	Conidia abundant on both surfaces.
2	4	4	7	10	No conidiophores on either surface.
			8	25	Conidiophores on both surfaces.
			10	75	Conidia few above and very abundant below. July 14, no change.
			16	57	Conidia very few above, numerous below.

[a] For convenience the decimal fractions, which make only a negligible difference in the averages, are omitted.

[b] In Table IV asterisks (*), daggers (†), and section marks (§) are used to designate definite leaf spots to which reference is made in the text.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
**2	6	1	July 7	15	Conidiophores forming above, nothing below.
			8	31	Conidiophores above, conidia very few below.
			10	100	Heavy production of conidia on both surfaces. July 12, 14, 16, 21, 23, no change.
			25	63	Conidia few above and numerous below.
3	2	1	June 24	10	No conidiophores on either surface. June 25, 26, 27, 28, 30, July 1, 2, 7 (leaf yellow), 8, no change.
3	2	2	25	10	No conidiophores on either surface. June 25, 26, 27, 28, 30, July 1, 2, 7, 8, no change.
3	4	1	July 7	10	No conidiophores on either surface.
			8	15	Conidiophores forming only on lower surface.
			10	62	Conidiophores abundant above and conidia abundant below.
			12	100	Conidia abundant on both surfaces. July 14, no change.
			16	69	Conidia very few above and abundant below.
			21	25	No conidia on either surface.
**3	8	1	7	10	No conidiophores on either surface. July 8, no change.
			10	25	Conidiophores abundant on both surfaces.
			12	100	Conidia abundant on both surfaces. July 14, 16, 21 (center of spot gone), no change.
			23	94	Conidia fairly abundant above and abundant below.
			25	50	Conidia few on both surfaces, leaving and leaf yellowing.
**3	8	2	7	10	No conidiophores on either surface. July 8, no change.
			10	25	Conidiophores abundant on both surfaces.
			12	100	Conidia abundant on both surfaces. July 14, no change.
			16	94	Conidia fairly abundant above and abundant below.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	50	Conidia few on both surfaces.
†3	8	3	7	10	No conidiophores on either surface. July 8, no change.
			10	25	Conidiophores abundant on both surfaces.
			12	100	Conidia abundant on both surfaces. July 14, no change.
			16	94	Conidia fairly abundant above and abundant below.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	75	Conidia few above and abundant below.
3	9	1	23	20	Conidiophores numerous above and few below.
			25	44	Conidia few above and very few below.
			28	50	Conidia few and matted together on both surfaces.
4	1	1	June 24	10	No conidiophores on either surface. June 25 (leaf dying), 26 (leaf dead), 27, 28, 30, July 1, no change.
4	3	1	July 8	10	No conidiophores on either surface.
			12	62	Conidia fairly numerous on both surfaces.
			14	50	Conidia leaving, few on both surfaces. July 16, 21 (leaf dead), no change.
**4	5	1	June 30	10	No conidiophores on either surface. July 1, 2, no change.
			July 7	30	Conidia forming on both surfaces. July 8, no change.
			10	25	Only conidiophores on both surfaces.
			12	100	Conidia abundant on both surfaces. July 14, no change.
			16	88	Conidia fairly abundant on both surfaces. July 21, 23, no change.
			25	50	Conidia few on both surfaces.
*4	12	1	21	50	Conidia few on both surfaces. July 23, no change.
			25	76	Conidia numerous on both surfaces.
5	1	2	1	10	No conidiophores on either surface. July 2, 7, 8, no change.
5	2	1	2	10	No conidiophores on either surface. July 7, no change.
			8	20	Conidiophores forming only on upper surface.
			10	30	Conidiophores above and conidia forming below.
			12	50	Conidia few on both surfaces.
			14	50	Conidia very few above, and fairly numerous below.
			16	50	Leaf dead, no change in spot.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
†5	4	3	July 7	20	No conidiophores above, very few conidia forming below.
			8	37	Conidiophores on upper surface, few conidia on lower.
			10	88	Conidia numerous above and very abundant below.
			12	75	Conidia few above and abundant below. July 14, no change.
			21	100	Conidia abundant on both surfaces. July 23 (leaf yellow), July 25, no change.
			28	63	Conidia few above and numerous below.
5	4	5	8	25	Conidiophores on both surfaces.
			10	37	Conidia few above and conidiophores below. July 12, no change.
			14	50	Conidia few on both surfaces.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	50	Conidia few on both surfaces.
			28	25	No conidia on either surface.
**5	6	1	7	17	Conidiophores none above and forming below.
			8	25	Conidiophores on both surfaces.
			10	75	Conidia few above and very abundant below. July 12, 14, 16, no change.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	57	Conidia very few above and numerous below.
			28	37	Conidia none above and few below.
5	8	4	14	10	No conidiophores on either surface.
			16	17	Conidiophores none above and forming below.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	75	Conidia abundant above and few below.
*5	8	5	23	25	Conodiophores on both surfaces.
			25	75	Conidia numerous on both surfaces.
5	10	1	7	40	Conidia very few on either surface but more on lower. July 8, no change.
			10	75	Conidia few above and abundant below.
			12	100	Conidia abundant on both surfaces. July 14, 16, 21, no change.
5	10	2	7	35	Conidiophores forming above and conidia few below. July 8, no change.
			10	62	Conidiophores well developed above and conidia abundant below.
			12	70	Conidia very few above and abundant below.
			14	75	Conidia few above and abundant below. July 16, no change.
			21	100	Conidia abundant on both surfaces. July 23, no change.
5	10	3	14	10	No conidiophores on either surface.
			16	17	Conidiophores above and none below.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	63	Conidia few above and numerous below.
*5	12	1	23	25	Conidiophores on both surfaces.
			25	70	Conidia very few above and abundant below.
			28	63	Conidia few above and numerous and matted below.
6	1	1	June 24	10	No conidiophores on either surface.
			25	20	Conidiophores very few above and abundant below. June 26, no change.
			27	31	Conidiophores above and conidia very few below. June 28, 30, July 1, 2 (leaf dying), no change.
			July 7	25	Conidiophores, but no conidia present.
7	6	1	7	10	No conidiophores on either surface.
			9	56	Conidia few above and fairly numerous below.
			10	62	Conidia none above and abundant below.
			12	100	Conidia abundant on both surfaces. July 14, 16, 21, 23, 25, no change.
7	6	3	10	15	Conidiophores forming on upper surface only.
			12	75	Conidia abundant above and few below.
			14	50	Conidia few on either surface. July 16, no change.
			21	100	Conidia abundant on both surfaces. July 23, 25, no change.
7	6	4	16	10	No conidiophores on either surface.
			21	100	Conidia abundant on both surfaces. July 23, 25, no change.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
*7	6	8	July 21	56	Conidia few above and fairly numerous below. July 23, no change.
			25	100	Conidia abundant on both surfaces.
*7	8	5	21	37	Conidia very few on both surfaces. July 23, no change.
			25	75	Conidia numerous on both surfaces.
			28	50	Conidia few on both surfaces. July 30, no change.
7	8	6	21	50	Conidia few on both surfaces.
			23	56	Conidia few above and fairly numerous below.
			25	63	Conidia numerous above and few below.
			28	50	Conidia few on both surfaces. July 30, Aug. 1, no change.
*7	8	7	July 23	15	Conidiophores none above and few below.
			25	75	Conidia few above and abundant below. July 28, 30, no change.
			Aug. 1	50	Conidia none above and numerous below.
7	8	12	July 25	25	Conidiophores on both surfaces.
			28	45	Conidia few forming on both surfaces.
			30	50	Conidia few on both surfaces. August 1, no change.
7	15	3	28	25	Conidiophores on both surfaces.
			30	63	Conidia few above and numerous below.
			Aug. 1	88	Conidia numerous above and abundant below.
†††8	8	5	July 9	10	No conidiophores on either surface.
			10	100	Conidia abundant on both surfaces.
*8	12	1	23	50	Conidia few on both surfaces.
			25	75	Conidia numerous on both surfaces. July 28, no change.
			30	88	Conidia numerous above and abundant below. August 1, no change.
			Aug. 5	75	Conidia numerous on both surfaces. Aug. 7, 9, 11, no change.
8	23	13	5	15	Conidiophores few above and none below. Aug. 7, no change.
			9	25	Conidiophores on both surfaces.
			11	57	Conidia numerous above and very few below.
			13	100	Conidia abundant on both surfaces.
†8	23	18	7	10	No conidiophores on either surface. Aug. 9, no change.
			11	60	Conidia abundant above and conidiophores few below.
			13	63	Conidia numerous above and few below. Aug. 15, 18, no change.
			22	100	Conidia abundant on both surfaces.
†8	24	1	July 28	75	Conidia numerous on both surfaces.
			30	62	Conidia fairly numerous on both surfaces. Aug. 1, no change.
			Aug. 5	44	Conidia few above and very few below.
			7	75	Conidia numerous and matted above and numerous below.
8	25	3	1	10	No conidiophores on either surface.
			5	44	Conidia very few above and few below.
			7	56	Conidia few above and fairly numerous below.
***8	29	1	1	10	No conidiophores on either surface.
			5	62	Conidia fairly numerous on both surfaces.
			7	75	Conidia numerous on both surfaces.
			9	50	Conidia few on both surfaces.
			11	56	Conidia few above and numerous below.
			13	100	Conidia abundant on both surfaces. Aug. 15, no change.
			18	75	Conidia few above and abundant below.
			22	88	Conidia numerous above and abundant below. Aug. 25, 28, no change.
			30	63	Conidia few above and numerous below. Sept. 1, no change except conidia matted above.
			Sept. 3	57	Conidia very few above and numerous below.
8	29	3	Aug. 5	25	Conidiophores on both surfaces.
			7	30	Conidiophores above and conidia forming below.
			9	50	Conidia very few above and fairly numerous below.
			11	100	Conidia abundant on both surfaces. Aug. 13, 15, 18, 22, 25, no change.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
***,†8	29	6	Aug. 5	20	Conidiophores very few on both surfaces. Aug. 7, no change.
			9	75	Conidia numerous on both surfaces. Aug. 11, no change.
			13	100	Conidia abundant on both surfaces. Aug. 15, no change.
			18	75	Conidia few above and abundant below.
			22	69	Conidia fairly numerous above and numerous below.
			25	100	Conidia abundant on both surfaces.
			28	87	Conidia fairly abundant on both surfaces.
			30	75	Conidia numerous on both surfaces.
			Sept. 1	69	Conidia fairly numerous above and numerous below.
			3	62	Conidia fairly numerous and matted above and fairly numerous below.
*** 8	29	8	Aug. 5	10	No conidiophores on either surface. Aug. 7, 9, no change.
			11	24	Conidia very few above and nothing below.
			13	88	Conidia abundant above and numerous below.
			15	94	Conidia fairly abundant above and abundant below.
			18	88	Conidia numerous above and abundant below.
			22	100	Conidia abundant on both surfaces.
			25	81	Conidia abundant above and fairly numerous and matted below.
8	29	9	5	35	Condiophores few above and conidia few below.
			7	50	Conidiophores numerous above and conidia numerous below.
			9	88	Conidia numerous above and abundant below.
			11	37	Conidia few above and none below.
			13	75	Conidia numerous and matted above and numerous below. Aug. 15, no change.
			18	88	Conidia numerous above and abundant below.
***,†8	29	11	7	10	Conidiophores few on both surfaces.
			9	44	Conidia very few above and few below.
			13	75	Conidia numerous on both surfaces. Aug. 15, no change.
			18	88	Conidia numerous above and abundant below.
			22	63	Conidia very few and matted above and fairly abundant below.
			25	88	Conidia numerous and matted above and abundant below.
			28	75	Conidia few above and abundant below.
			30	88	Conidia numerous and matted above and abundant below.
			Sept. 1	82	Conidia numerous and matted above and fairly abundant below.
			3	69	Conidia few and matted above and fairly abundant below.
			6	50	Conidia very few and matted above and fairly numerous and matted below.
			8	43	Conidia none above and fairly numerous and matted below.
§8	33	1	1	10	No conidiophores on either surface.
			5	81	Conidia fairly numerous and matted above and abundant below. Aug. 7, no change.
			9	69	Conidia fairly numerous and matted above and numerous below.
			11	63	Conidia numerous above and few below.
			13	100	Conidia abundant on both surfaces.
			15	81	Conidia fairly numerous and matted above and abundant below. Aug. 18, no change.
			22	63	Conidia few and matted above and numerous below. Aug. 25, no change.
			28	50	Conidia none above and numerous below.
			30	56	Conidia none above and fairly abundant below.
††8	35	9	13	10	No conidiophores on either surface.
			15	15	Conidiophores few above and none below.
			18	37	Conidia very few on both surfaces.
			22	44	Conidia very few above and few below.
			25	62	Conidia fairly numerous on both surfaces.
			28	69	Conidia numerous above and fairly numerous below. Aug. 30, Sept. 1, no change..
			3	62	Conidia fairly numerous and matted above and fairly numerous below.
			6	50	Conidia few and matted on both surfaces.
			8	37	Conidia very few on both surfaces. Sept. 11, no change except matted on both surfaces.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
††, §8	§35	10	Aug. 13	10	No conidiophores on either surface.
			15	15	Conidiophores very few above and none below. August 18, no change.
			22	37	Conidia very few on both surfaces.
			25	56	Conidia fairly numerous above and few below.
			28	50	Conidia fairly numerous above and very few below.
			30	88	Conidia numerous and matted above and abundant below. September 1, 3, 6, no change.
			Sept. 8	50	Conidia few and matted on both surfaces.
			10	37	Conidia very few and matted on both surfaces.
††, §8	§37	1	Aug. 11	24	Conidia very few above and nothing below.
			13	100	Conidia abundant on both surfaces. August 15, no change except conidia matted above.
			18	94	Conidia fairly abundant and matted above and abundant below.
			22	88	Conidia numerous above and abundant below. August 25, no change.
			28	75	Conidia numerous on both surfaces.
			30	69	Conidia fairly numerous above and numerous below. September 1, 3, no change.
			Sept. 6	37	Conidia very few on both surfaces.
			8	25	Conidia none on either surface. September 10, 13, 15, no change.
††8	37	2	Aug. 11	10	No conidiophores on either surface.
			13	100	Conidia abundant above and abundant and matted below.
			15	94	Conidia abundant above and fairly abundant below.
			18	87	Conidia fairly abundant on both surfaces.
			22	100	Conidia abundant on both surfaces. August 25, no change except slightly matted on both surfaces.
			28	94	Conidia abundant and matted above and fairly abundant below.
			30	100	Conidia abundant and matted on both surfaces.
			Sept. 1	87	Conidia fairly abundant and matted on both surfaces. September 3, 6, no change.
			8	57	Conidia very few above and fairly numerous below. September 10, no change.
			13	37	Conidia none above and few below. September 15, no change, conidia still matted on both surfaces.
††8	37	3	Aug. 11	10	No conidiophores on either surface.
			13	18	Conidiophores very few on both surfaces.
			15	44	Conidia very few above and few below.
			18	50	Conidia very few above and fairly numerous below.
			22	62	Conidia fairly numerous and matted above and fairly numerous below.
			25	62	Conidia fairly numerous on both surfaces.
			28	75	Conidia numerous on both surfaces. August 30, no change, conidia matted on both surfaces.
			Sept. 1	62	Conidia fairly numerous and matted on both surfaces.
§8	37	6	Aug. 18	10	No conidiophores on either surface.
			22	50	Conidia few on both surfaces.
			25	62	Conidia fairly numerous on both surfaces.
			28	75	Conidia fairly abundant in center on both surfaces.
			30	70	Conidia numerous in center above and fairly abundant in center blow. September 1, no change.
			Sept. 3	69	Conidia fairly numerous above and fairly abundant in center below.
			6	87	Conidia fairly abundant on both surfaces.
			8	75	Conidia fairly numerous and matted above and fairly abundant below. September 10, no change.
			13	94	Conidia fairly abundant above and abundant below. September 15, no change.
			17	50	Conidia few on either surface.
8	38	1	Aug. 11	10	No conidiophores on either surface.
			13	69	Conidia numerous above and fairly numerous below.
			15	69	Conidia fairly numerous above and numerous and matted below.
			18	82	Conidia fairly abundant above and numerous and matted below.
			22	69	Conidia numerous and matted above and fairly numerous below.
8	39	6	Aug. 18	10	No conidiophores on either surface.
			22	63	Conidia numerous above and few below.
			25	82	Conidia fairly abundant above and numerous below.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
8	41	3	Aug. 22	31	Conidiophores above and conidia very few below.
			25	62	Conidia fairly numerous on both surfaces.
			28	82	Conidia numerous above and fairly abundant below.
			30	88	Conidia numerous above and abundant below. September 1, no change.
			Sept. 3	74	Conidia fairly numerous above and fairly abundant below.
			6	69	Conidia fairly numerous and matted above and numerous and matted below. September 8, 10, no change.
			13	57	Conidia very few and matted above and numerous below. September 15, 17, no change.
			19	50	Conidia none above and numerous below.
††, §8	44	1	Aug. 25	10	No conidiophores on either surface.
			28	24	Conidia very few above and nothing below.
			30	44	Conidia few above and very few below. September 1, 3, 6, no change.
			Sept. 8	50	Conidia few on both surfaces.
			10	56	Conidia fairly numerous above and few below.
			13	44	Conidia very few above and few below.
			15	69	Conidia fairly numerous and matted above and numerous below.
			17	44	Conidia very few and matted above and few below.
			19	31	Conidia none above and very few below.
††8	44	2	Aug. 25	15	Conidiophores forming above and nothing below.
			28	75	Conidia fairly abundant in center of both surfaces.
			30	90	Conidia abundant in center of both surfaces. September 1, 3, 6, no change.
			Sept. 8	69	Conidia fairly numerous above and numerous below.
			10	100	Conidia abundant on both surfaces. September 13, 15, no change.
			17	56	Conidia few and matted above and fairly numerous and matted below.
			19	50	Conidia very few and matted above and fairly numerous and matted below.
8	44	3	Aug. 25	10	No conidiophores on either surface.
			28	80	Conidia fairly abundant in center on both surfaces.
			30	90	Conidia fairly abundant in center above and abundant in center below. September 1, 3, no change.
			Sept. 6	87	Conidia fairly abundant and matted above and fairly abundant below. September 8, no change.
			10	94	Conidia fairly abundant above and abundant below. September 13, no change.
			15	88	Conidia numerous and matted above and abundant below.
			17	75	Conidia fairly numerous and matted above and fairly abundant below.
			19	63	Conidia few and matted above and numerous below.
††, §8	45	1	Aug. 22	37	Conidia very few on both surfaces.
			25	56	Conidia few above and fairly numerous and matted below.
			28	82	Conidia numerous and matted above and fairly abundant below.
			30	88	Conidia numerous above and abundant below. September 1, no change.
			Sept. 3	81	Conidia fairly numerous and matted above and abundant below. September 6, 8, no change except conidia matted below.
			10	75	Conidia fairly numerous and matted above and fairly abundant and matted below.
			13	69	Conidia few and matted above and fairly abundant and matted below.
			15	50	Conidia none above and numerous and matted below.
			17	31	Conidia none above and very few and matted below.
			19	25	Conidia none on either surface.
8	45	2	Aug. 25	10	No conidiophores on either surface.
			28	35	Conidia few above and conidiophores forming below.
			30	25	Conidia very few above and nothing below.
			Sept. 1	29	Conidia very few above and few conidiophores below. September 3, no change.
			6	44	Conidia few above and very few below.
			8	50	Conidia few and matted above and few below.
			10	44	Conidia few and matted above and very few below. September 13, 15, 17, no change.
			19	25	Conidia none on either surface.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
8	45	5	Aug. 25	10	No conidiophores on either surface.
			28	56	Conidia few above and fairly numerous below. August 30, September 1, 3, no change.
			Sept. 6	65	Conidia few and matted above and fairly abundant in center below.
			8	58	Conidia few and matted above and numerous in center below.
			10	69	Conidia few and matted above and fairly abundant below.
			13	63	Conidia few and matted above and numerous in center below. September 15, no change.
8	49	1	Aug. 28	37	Conidia very few on both surfaces.
			30	50	Conidia few on both surfaces. September 1, 3, no change.
			Sept. 6	69	Conidia numerous above and fairly numerous below.
			8	62	Conidia fairly numerous and matted above and fairly numerous below.
			10	75	Conidia numerous and slightly matted on both surfaces.
			13	56	Conidia fairly numerous and matted above and few below.
8	49	2	Aug. 28	10	No conidiophores on either surface.
			30	25	No conidiophores above and conidia very few below. September 1, 3, no change.
			Sept. 6	56	Conidia few above and fairly numerous below.
			8	50	Conidia very few above and fairly numerous below. September 10, 13, no change.
8	49	3	Aug. 28	10	No conidiophores on either surface.
			30	15	Conidiophores few above and very few below.
			Sept. 1	30	Conidiophores few above and conidia very few below. September 3, no change.
			6	62	Conidia fairly numerous on both surfaces.
			8	65	Conidia fairly numerous above and numerous in center below.
			10	75	Conidia numerous above and numerous and matted in center below.
			13	62	Conidia fairly numerous on both surfaces.
8	49	6	1	10	No conidiophores upon either surface. September 3, no change.
			6	44	Conidia very few above and few below. September 8, no change.
			10	50	Conidia few on both surfaces. September 13, no change.
8	49	7	1	10	No conidiophores on either surface. September 3, no change.
			6	24	Nothing above and conidia very few below.
			8	44	Conidia very few above and few below. September 10, 13, no change.
8	49	8	1	10	No conidiophores on either surface. September 3, 6, no change.
			8	20	Nothing above and conidia forming below.
			10	44	Conidia very few above and few below. September 13, no change.
8	49	9	3	10	No conidiophores on either surface. September 6, no change.
			8	20	Nothing above and very few conidia forming below.
			10	44	Conidia very few above and few below. September 13, no change.
8	49	10	3	10	No conidiophores on either surface. September 6, 8, no change.
			10	37	Conidia very few on both surfaces. September 13, no change.
8	51	1	3	10	No conidiophores on either surface. September 6, no change.
			8	24	Conidia very few above and nothing below. September 10, no change.
			13	37	Conidia very few upon both surfaces. September 15, 17, no change.
8	51	2	6	10	No conidiophores on either surface.
			8	37	Conidia very few on both surfaces.
			10	65	Conidia numerous in the center upon both surfaces. September 13, 15, no change.
			17	44	Conidia very few above and few below.
8	51	3	6	10	No conidiophores on either surface. September 8, no change.
			10	37	Conidia very few on both surfaces.
			13	44	Conidia few above and very few below. September 15, 17, no change.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
8	51	4	Sept. 6	10	No conidiophores on either surface. September 8, 10, no change.
			13	30	Conidiophores forming above and conidia very few below. September 15, 17, no change.
8	51	5	6	10	No conidiophores on either surface. September 8, 10, 13, 15, 17, no change.
8	51	6	6	10	No conidiophores on either surface. September 8, 10, 13, no change.
			15	15	Conidiophores none above and forming below.
			17	24	Nothing above and very few conidia below.
8	53	1	17	10	No conidiophores on either surface. September 19, no change.
8	53	2	17	10	No conidiophores on either surface. September 19, no change.
9	3	1	June 24	10	No conidiophores on either surface. June 25, 26, 27, 28, 30; July 1, 2, 7, no change.
9	3	2	July 9	10	No conidiophores on either surface.
			10	25	Conidiophores abundant on both surfaces.
			12	87	Conidia fairly abundant on both surfaces. July 14, no change.
			16	100	Conidia abundant on both surfaces.
			21	37	Leaf dead, conidia very few on both surfaces. July 25, 28, no change.
9	5	1	21	50	Conidia few on both surfaces. July 23, 25, no change.
			28	37	Conidia none above and few below. July 30, no change.
9	5	2	23	17	Conidiophores above and none below.
			25	75	Conidia numerous on both surfaces. July 28, 30, no change.
9	7	1	9	10	No conidiophores on either surface.
			10	37	Conidia few above and conidiophores abundant below.
			12	94	Conidia abundant above and fairly abundant below. July 14, 16, no change.
10	3	1	June 30	10	No conidiophores on either surface. July 1, 2, 7, 9, 10, 12, no change.
10	5	1	July 2	10	No conidiophores on either surface.
			7	20	Conidiophores few above and abundant below.
			9	37	Conidiophores above and conidia few below.
			10	75	Conidia numerous on both surfaces. July 12, 14, no change.
			16	100	Conidia abundant on both surfaces. July 21, 23, no change.
			25	75	Conidia few above and abundant below.
			28	50	Conidia none above and numerous below. Leaf dead. July 30, no change.
10	5	3	21	50	Conidia few on both surfaces. July 23, no change.
			25	56	Conidia fairly numerous above and few below.
			28	25	Conidia none on either surface. July 30, no change.
10	5	4	21	37	Conidiophores above and conidia few below.
			23	44	Conidia very few above and few below.
			25	37	Conidia very few on both surfaces.
			28	25	Conidia none on either surface. July 30, no change.
10	6	1	2	10	No conidiophores on either surface.
			7	31	Conidia very few above and conidiophores below.
			9	62	Conidia fairly numerous on both surfaces. July 10, 12, 14, no change.
			16	50	Conidia few above and fairly numerous below.
10	6	6	July 12	10	No conidiophores on either surface.
			14	15	Conidiophores none above and very few below.
			16	37	Conidiophores above and conidia few below.
			21	100	Conidia abundant on both surfaces. July 23, 25, 28, 30, no change.

TABLE IV.—*Data on life histories of a representative number of leaf spots studied on 10 plants in a medium-early sugar-beet field near Rocky Ford, Colo., during the season of 1913*—Continued

Plant No.	Leaf No.	Spot No.	Date.	Graph values.	Data on life histories.
			1913.		
**10	9	1	July 7	50	Conidia few on both surfaces. July 9, no change.
			10	75	Conidia few above and abundant below.
			12	94	Conidia fairly abundant above and abundant below. July 14, no change.
			16	69	Conidia very few above and abundant below.
			21	100	Conidia abundant on both surfaces. July 23, no change.
			25	75	Conidia numerous on both surfaces.
†10	9	2	7	37	Conidiophores above and conidia few below. July 9, no change.
			10	75	Conidia few above and abundant below.
			12	69	Conidia few above and fairly abundant below. July 14, no change.
			16	69	Conidia very few above and abundant below.
			21	100	Conidia abundant on both surfaces. July 23, 25, no change.
10	9	3	23	25	Conidiophores on both surfaces.
			25	75	Conidia numerous on both surfaces. July 28, no change.
*10	10	1	23	10	No conidiophores on either surface.
			25	75	Conidia numerous on both surfaces.
			28	75	Conidia abundant above and few and matted below. July 30, no change.
10	11	1	25	75	Conidia numerous on both surfaces.
			28	75	Conidia abundant above and few and matted below. July 30, no change.
10	11	3	25	50	Conidiophores above and conidia numerous below.
			28	75	Conidia numerous on both surfaces. July 30, no change.

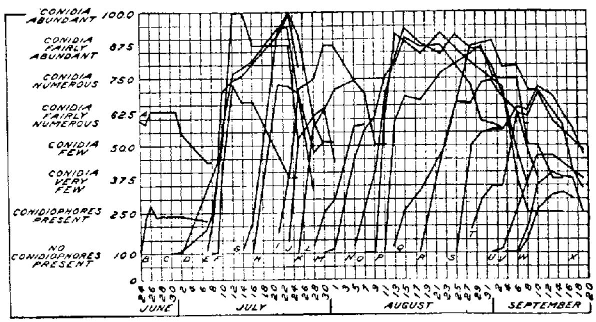

FIG. 6.—Curves of the leaf spot history series, showing the production of conidia on different dates from June 24 to September 19, 1913, at Rocky Ford, Colo.

After the values were all assigned, the spots which appeared on or about the same day were brought together in 24 groups and averaged (Table V and fig. 6). The temperature and humidity records used in the correlations with the leafspot histories were taken among the sugar-beet leaves near the surface of the ground.

TABLE V.—*Leafspot history series showing their arbitrary values on different dates and the number of spots entering into the average of each series at Rocky Ford, Colo., 1913*

Date.	Series and values.																							
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
June 24	59	11																						
25	57.5	23																						
26	62.5	27.5																						
27	62.5	23																						
28	62.5	23.5																						
30	62.5	23.5	10																					
July 1	62.5	23.5	10																					
2	54	23.5	10	10																				
7	43.5	21.5	19	34	11																			
8	43.5		24		20.5	10																		
9				43		10																		
10			50	70	56	41																		
12			100	74	77	73																		
14			100	76	79	66	11																	
16			87.5	80.5	81.5	66	21	10																
21			87.5	91	94	46	93.5	72.5	17.5															
23			87.5	100	94.5	37.5	100	72	37.5	14														
25			50	91.5	69	37.5	79	69	71	52	10													
28				58.5	33			47	75	61	58.5	12.5												
30				50				51	87.5	64	63	25	10											
Aug. 1								50.5	87.5	43.5	70.5	29.5	11.5											
5									75		75	57	45	12.5										
7									75		69.5	57.5	55.5	26	10									
9									75		50		60.5	39	10									
11									75		50		75.5	66.5	61.5	10								
13													80.5	82	92	58.5	12							
15													90.5	94	89	68	25.5							
18													87	88	84.5	67	33	10.5						
22													87.5	84	92.5	77	46.5	44.5						
25													79.5	91.5	86	81	65.5	65.5	10.5					
28													72	86	81	84	65.5	87.5	50.5	19				
30													59	86	78	87.5	73.5	88	54.5	29.5				
Sept. 1													58	79.5	75	75	75	80.5	55.5	34.5	10			
3													56	68.5	71.5	75	68.5	79.5	55.5	34.5	10	10		
6														47	37.5	75	62.5	79.5	64	62.5	26	10	10	
8														34	25	50	48	70.5	63	61	36	19	15.5	
10															25	50	37.5	70.5	71.5	70	46	35	26	
13															25	37.5		62.5	68.5	59	46	39.5	31	
15															25	37.5		57.5	61.5			37.5	32	
17																		40.5	56			37.5	30	10
19																		33.5	46.5	48	37.5	25		10
Average number of spots	4	6	6	29	28	7	4	22	8	18	24	9	72	13	6	7	18	14	9	4	3	3	5	5

CONIDIAL PRODUCTION.—Under favorable conditions conidia are produced apparently much more readily by young than by old leafspots. For instance, as will be seen in Table IV, leaf spots (*)[1] 2 to 4 days old showed a marked increase in conidial production from July 23 to 25, while during the same period spots (**) 14 to 24 days old in most cases showed a decrease. However, spots (***) 2 to 3 weeks old on green leaves showed an increased production from August 18 to 25, the conditions being favorable, and some (†) even produced a second and third crop, although usually but one crop (††) is produced and this while the spots are comparatively young. It was also found that under favorable conditions a spot (†††) may produce abundant conidia on both surfaces in one day. Usually the maximum production is reached within 10 days after the spots appear (fig. 6), and sometimes under very favorable conditions the production may increase after this period (fig. 6, curves D and E, July 17 to 23), but the older spots do not always respond to favorable conditions in this way (fig. 6, curves C and F). In no case was a new growth of conidia observed on spots on yellow or dying leaves on green plants in the field. The fungus seemed to lose its vigor much sooner on such leaves than on green leaves which remained attached to the crown at harvest time. From the standpoint of control of the disease this is a very important point, from the fact that at harvest time the green leaves, on which the fungus is vigorous, are removed with the crowns and stored in the silo, while the yellow and dying leaves, on which the fungus may be too weak to overwinter, break off and remain on the ground.

During the greater part of August and September, when the precipitation was light (fig. 7), many of the conidia had a shrunken appearance and were massed together on the leafspot areas (Table IV, §). When placed in water, these conidia did not germinate; consequently this desiccation of the conidia may also be an important factor in connection with the vitality of the fungus on the host.

The position of the leaf on which the spot studied was located was also found to be an important factor in conidial production, an abundance of conidia being frequently observed on leaves protected from the sun, while at the same time few were observed on those exposed to the sun the greater part of the day. This difference in production is thought to be due mainly to the difference in humidity of the protected and the exposed locations.

A study of the comparative production of conidia on the upper and the lower surfaces of the spots was also made, the conidia on the spots included in series E, K, N, and S (fig. 6) being tabulated for this purpose.

Generally a more abundant conidial production was found on the lower than on the upper surface (fig. 8), and this was due apparently to

[1] The asterisks (*), daggers (†), and section marks (§) refer to particular leaf spots in Table IV.

the probably higher humidity of the former. Only during a very favorable period (fig. 7, July 19 to 21) or where the leaves were turned up or protected by other leaves was the conidial production on the upper surface equal to that on the lower surface (fig. 8, series E, July 21). At times, conidia were formed more abundantly on the upper surface than on the lower (fig. 6, series N, August 11, and series S, August 28). Because of the spongy parenchyma and the greater number of stomata on the lower surface, it might be supposed that conidiophores could be produced more readily on this than on the upper surface; but, as above indicated, humidity would seem to be the controlling factor in this connection.

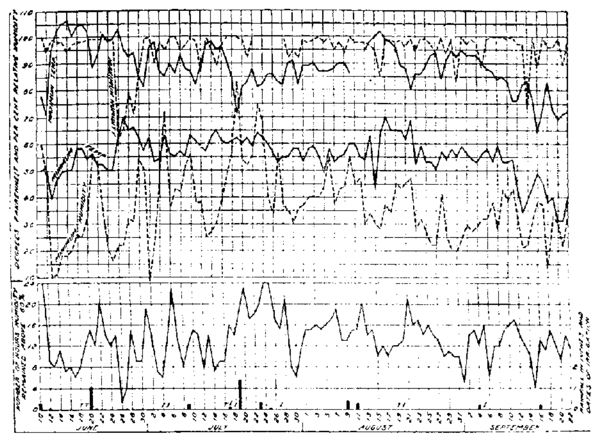

FIG. 7.—Curves of the maximum and minimum temperatures and humidities, the number of hours that the humidity remained above 60 from noon of the preceding to noon of the given day among the plants, and rainfall and irrigation records, taken in a medium-early sugar-beet field from June 20 to September 22, 1913, at Rocky Ford, Colo.

A comparison of the conidial production as shown in Table IV and figure 6 and the climatic data shown in figure 7 indicates many definite relations. When the spots were first found, on June 20 and 24, conidia were fairly numerous (fig. 6, curve A) on all except six spots, which had evidently just developed on the latter date, as no conidia were present at this time and conidiophores only were produced the next two weeks. The following week there was but little increase, and during the next few days many of the conidia were disseminated. The small production of conidia was evidently due directly to the high temperature and the low humidity which prevailed during this period (fig. 7), as conidia were produced in great abundance from July 9 to 12 (fig. 6, curves C, D, E, F), when the temperature was lower and the humidity higher (fig. 7). Dur-

ing this time and the few days just preceding, the humidity remained above 60 for a longer time on an average and the minimum humidity did not become so excessively low nor the temperature so excessively high as during the time previous to July 4.

The next period of pronounced increase in conidial production was from July 19 to 23 (fig. 6, curves D, E, G), when the conditions were more favorable than during any period of similar length through the summer, the humidity ranging above 60 on an average of 19.4 hours each day and not falling below 52 (fig. 7), and the temperature ranging from 60° to 90° F.

Conidial production was again above the average (curves M, N, and O) from August 9 to 13, during which period the humidity remained above 60 from 13 to 20 hours each day and there was a small amount of rain which seemed to aid in maintaining the necessary humid conditions. Production was checked on August 16, on which date the temperature was 102° and the average humidity low, and was again inhibited after

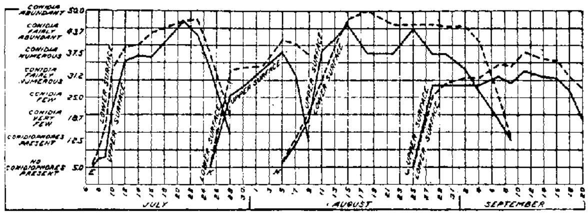

FIG. 8.—Curves of the comparative production of conidia on the upper and lower surfaces of the leaf spots, representing series E, K, N, and G of Table V and figure 6. Rocky Ford, Colo., 1913.

September 11, subsequent to which date the minimum temperatures ranged from about 30° to 45° and the maximum from about 65° to 83°, while the humidity remained above 60 for 12.4 hours per day, on an average.

The general conclusion from these tests is that conidial production is greatly influenced by temperature and relative humidity, or speaking specifically—

(1) A temperature of 100° F. or over is detrimental to conidial production, directly perhaps because it is inimical to the growth of the fungus and indirectly because humidity is ordinarily excessively low at such an extreme temperature.

(2) Conidial production is greatly checked at daily temperatures ranging below 50° as a minimum and 80° as a maximum.

(3) The most favorable temperature for conidial production is 80° to 90° in the daytime and not below 60° at night.

(4) The temperature being favorable, the largest conidial production occurred at the higher humidities. A good production occurred when

the humidity remained above 60 for not less than 15 to 18 hours, but very few were produced when the humidity remained above 60 for less than 10 to 12 hours daily.

With a view to determining the approximate number of conidia produced on a sugar-beet plant under a favorable temperature and humidity, one representing a heavy infection in August was selected. After the infected leaves were measured a representative portion of conidia were carefully washed off into sterilized water and counted. The count, which was made by means of a dilution method, showed 250,000,000 conidia on the plant at that time.

CONIDIAL DISSEMINATION.—That a period of low humidity, with its accompanying factors, is favorable to the dissemination of conidia was frequently observed (fig. 6, curve R). For instance, it was found that the amount of conidia diminished on September 1, 6, 14, and 15, when the humidity remained above 60 for 5, 6, 10, and 4 hours, respectively; while, on the other hand, there was no diminution in the amount present on September 3 to 5 and 8 to 10, during which periods the humidity remained above 60 for 12 to 16 hours.

Rainfall is also an important factor in the dissemination of conidia, as was noted in several instances. On July 19 (fig. 6, curve F) rain fell, and as a result many conidia were washed off, and the same was true in the case of rains on July 23 (curves C, D, E, G, H), August 9 (curve K), September 4 (curves N, O, R), and September 16 (curves Q, S, T, U, V, W). After rains on July 19, August 9, and September 4, however, there were more conidia present than before, but this was probably due to the fact that more were produced under the favorable humid conditions attending these rains than were washed off. It was also found that the conidia were disseminated more rapidly from the upper than from the lower surface of the spots (fig. 8). This was due probably to the greater exposure of the former to wind and rainfall.

RELATION OF INFECTION CYCLES TO CLIMATIC CONDITIONS

For the purpose of determining the relation of infection cycles to climatic conditions, a study was made of the increase and spread of disease in a field of sugar beets planted about May 1 [1] at Rocky Ford and one planted about two weeks later. Both fields had been in beets for two or three years, and as very few, if any, of the tops were removed after the harvest of 1912, infection appeared early in 1913 and was generally distributed.

Three plants in the early field (Table VII) and ten in the medium-early (Table VI) were selected, the leaves tagged and numbered consecutively, beginning with the outermost or oldest and continuing with the new ones as they appeared. The spots on each leaf were counted at

[1] Conidial production and dissemination were also studied in this field.

frequent intervals,[1] and the average actual increase of spots per plant computed (Table VIII and fig. 9). It was found that from 400 to 1,000 spots on a leaf, depending on its size, killed it within a few days.

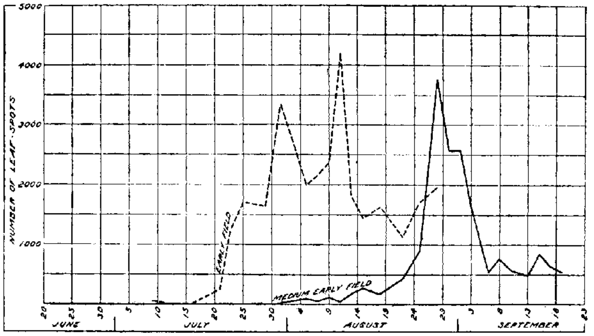

FIG. 9.—Curves of the 2-day average increases in the number of leaf spots per plant in a medium-early and an early sugar-beet field, from June 18 to September 19, 1913, at Rocky Ford, Colo.

TABLE VI.—*Average infection cycle of Cercospora beticola in a medium-early sugar-beet field with poorly developed foliage and with a consequent low humidity early in the season at Rocky Ford, Colo., in 1913*

Date.	Total number of leaves marked.	Total number of leaves infected.	Total number of leaves dead.	Number of leaves killed by *Cercospora beticola*.	Number of infected green and dying leaves.	Number of functional leaves— Infected.	Number of functional leaves— Uninfected.	Total number of functional leaves.	Total number of leaf spots per plant.	Average number of leaf spots per leaf.
July 2	14.2	3.2	3.3	....	3	2.9	8	10.9	5	1.6
[illegible]	16.8	4.7	3.8	....	4.4	4.1	8.9	13	10.4	2.3
8	17.4	5.4	4.3	....	4.7	4.4	8.7	13.1	11.4	2.4
10	18.5	5.5	4.6	....	4.5	4.3	9.6	13.9	11.2	2.4
1[illegible]	19.7	5.5	5.1	....	4.3	4	10.6	14.6	10.8	2.5
1[illegible]	21.3	5.8	5.5	....	4.3	4	11.8	15.8	10.8	2.5
1[illegible]	22.6	6	6.1	....	4.1	3.8	12.7	16.5	10.4	2.5
2[illegible]	26.3	6.6	7.1	....	4.4	3.5	15.7	19.2	13.3	3
2[illegible]	27.5	7.8	8	....	4.7	4.1	15.4	19.5	17.2	3.6
2[illegible]	29	8.1	8.9	....	4.4	3.5	16.6	20.1	17.5	3.9
2[illegible]	30.5	10.8	9.3	....	6.3	5.8	15.4	21.2	20.5	3.2
3[illegible]	33	17.6	11	....	10.7	10.3	11.7	22	42	3.9
Aug. [illegible]	34	27	12	....	20	19	3	22	93.5	4.7
[illegible]	35.5	27	12.5	....	19	18.5	4.5	23	292	15.[illegible]
[illegible]	36.5	27	13.5	....	18.5	17.5	5.5	23	355	19.1
[illegible]	37.5	29	13.5	....	19.5	19.5	4.5	24	402	20.6
11	38.5	30	15.5	....	20.5	19	4	23	455.5	22.2
1[illegible]	40	31	15.5	....	20	20	4.5	24.5	593	29.6
15	41.5	31.5	15.5	....	20.5	20.5	5.5	26	875	4[illegible].6
1[illegible]	43	33.5	15.5	....	22.5	22.5	5	27.5	1,155.5	51.3
2[illegible]	45	35.5	15.5	....	24.5	24.5	5	29.5	2,045.5	85.9
2[illegible]	46	38	15.5	....	27	27	3.5	30.5	3,420	120.6
2[illegible]	48	41	17	1.5	29.5	28	3	31	9,081.5	307.8
3[illegible]	48.5	41	18	2	28.5	27.5	3	30.5	10,856	380.9
Sept. [illegible]	50	41.5	23.5	6	25.5	22.5	4	26.5	12,371.5	485.1
[illegible]	50.5	42.5	25.5	8	23.5	21.5	4	25	11,493	489
[illegible]	51.5	42.5	26.5	9	21.5	20.5	5	25	10,928.5	508.3
10	52.5	44.5	28.5	11	22.5	20.5	4.5	24	10,782	479.2
1[illegible]	53	44.5	30	12.5	20.5	19	4	23	10,003.5	487.9
1[illegible]	53.5	44.5	32.5	15	19	16.5	4.5	21	9,585.5	504.5
1[illegible]	54	45.5	34.5	17	17.5	15.5	4	19.5	8,504	485.9
19	55	45.5	35	17.5	15.5	15	5	20	7,597.5	490.1

[1] For convenience and uniformity, 2-day averages were used in making the comparisons, the counts being made usually at 2-day intervals.

TABLE VII.—*Average infection cycle of Cercospora beticola in an early sugar-beet field in which there was a heavy production of foliage and a consequent high humidity early in the season at Rocky Ford, Colo., in 1913*

Date.	Total number of leaves marked.	Total number of leaves infected.	Total number of leaves dead.	Number of leaves killed by *Cercospora beticola*.	Number of infected green and dying leaves.	Number of functional leaves— Infected.	Uninfected.	Total number functional leaves.	Total number of leaf spots per plant.	Average number of leaf-spots per leaf.
July 7	23	13.5	4	....	12	12	7	19	529	44
9	24	13.5	4.5	....	12	11.5	8	19.5	596.5	49.7
12	26	14	5.5	....	12	11	9	20.5	615	51.2
14	27.5	14.5	5.5	....	11.5	11.5	10.5	22	554.5	48.2
16	29.5	16	7	....	13	11.5	10.5	22.5	574.5	44.2
21	34.5	23	8.5	....	18.5	17	9	26	1,113.5	60.2
23	37	29	10.5	....	23	21	5.5	26.5	2,216.5	96.3
25	38.5	30	11	....	22	21.5	6	27.5	3,776.5	171.6
29	41.5	31	11.5	....	22.5	22	8	30	7,045.5	313.1
Aug. 1	44	37	15	3	28	24.5	4.5	29	11,966.5	427.3
5	46.5	39	16	4	26.5	25.5	5	30.5	12,638	476.9
7	48.5	40	18	6	26.5	24.5	6	30.5	13,905	524.7
9	50	42	20	8	26.5	24.5	5.5	30	14,228.5	536.9
11	51.5	42	21.5	9.5	24.5	23.5	7	30	16,386	668.8
13	53.5	42.5	24.5	12.5	23.5	20.5	8.5	29	16,693	710.3
15	55.5	45	29.5	17.5	23	18	8	26	14,993	651.8

TABLE VIII.—*Actual and 2-day average increase in the number of leaf spots per plant in a medium-early and an early sugar-beet field from June 18 to September 19, at Rocky Ford, Colo., in 1913*

Date.	Increase in medium-early field. Actual.	2-day average.	Increase in early field. Actual.	2-day average.	Date.	Increase in medium-early field. Actual.	2-day average.	Increase in early field. Actual.	2-day average.
June 20	0.3	0.3	....	....	Aug. 5	203	102	3,996	1,998
22	.5	.5	....	....	7	65	65	2,167	2,167
24	0	0	....	....	9	127	127	2,373	2,373
26	.3	.3	....	....	11	53	53	4,208	4,208
28	.1	.1	....	....	13	190	190	1,831	1,831
30	.4	.4	....	....	15	282	282	1,450	1,450
July 2	2.3	2.3	....	....	18	280	186	2,450	1,633
7	4.9	1.9	....	....	22	895	447	2,286	1,143
8	1.4	2.8	....	....	25	1,379	919	2,582	1,722
9	....	....	70	70	28	5,664	3,776	2,944	1,962
10	.9	.9	....	....	30	2,572	2,572	....	....
12	.2	.2	18.5	12.2	Sept. 1	2,582	2,582	....	....
14	.7	.7	24.5	24.5	3	1,634	1,634	....	....
16	.7	.7	20.5	20.5	6	799	532	....	....
21	3.3	1.3	672	269	8	771	771	....	....
23	3.3	3.3	1,272	1,272	10	578	578	....	....
25	1.9	1.9	1,723	1,723	13	732	488	....	....
28	4.9	3.2	....	....	15	857	857	....	....
29	....	....	3,282	1,641	17	635	635	....	....
30	5.1	5.1	....	....	19	543	543	....	....
Aug. 1	44	44	4,978	3,318					

The period of incubation of the fungus being from 11 to 13 days, as shown by artificial infection experiments, a corresponding increase in the number of spots on the leaves would not necessarily follow immediately after a period during which conditions favorable for infection prevailed.

Notwithstanding the early appearance of the spots in the medium-early field—on June 20—and a consequent expectation of an epidemic of the disease, the increase in infection was very light (Table VIII)

during the latter part of June and early part of July. This was doubtless due to the fact that during this period the stomata were closed against the fungus the greater part of the day on account of the excessively high temperature, which was generally above 100° F., and the excessively low humidity, which at one time fell to 10 and which was only above 60 from 6 to 15 hours a day, and also to the fact that a temperature as high as 95° inhibits the growth of the fungus and kills it after a few days.

After July 5 the temperature was lower and the humidity higher than during the period above mentioned. As a result, numerous conidia were produced from July 9 to 12, and at the end of the period of incubation—July 21 to 25—there was a slight increase in the number of spots (Table VIII). Rains between July 19 and 25 and the resulting high humidity caused a rather marked increase in the number of spots in late July and early August, these spots appearing on many leaves hitherto uninfected (Table VI). Prior to this period the number of leaves showing spots were comparatively few, but after July 30 the majority showed spots, and the proportion of infected to uninfected leaves gradually increased until August 28, after which it decreased. During the period from July 30 to August 28 the humidity was comparatively high, remaining above 60 on an average of 14.6 hours on all except three days, on which it remained above 60 for 10 hours; and the maximum and minimum temperatures generally were not above 90 nor below 55, respectively. The increased proportion of infected to uninfected leaves during this period, however, was not necessarily due to increasingly favorable climatic conditions but to the cumulative effect of the organism, the amount of viable conidia and consequent new infections increasing as the number of spots increased, as shown by the enormous increase of 3,776 spots per plant on August 27 and 28. After September 3 the increase in infection was considerably less (fig. 9). This was due apparently to the fall in temperature, the maximum being rarely above 76° F and the minimum seldom above 50° after September 8, while the humidity was comparatively favorable.

The increase in infection through the season was considerably higher in the early than in the medium-early sugar-beet field, as shown by the total amount of the disease (Tables VI and VII) and the actual increase (Table VIII and fig. 9). This was due to the fact that the foliage was heavier in the early than in the medium-early field (Tables VI and VII, functional leaves), and consequently the humidity was higher and the infection greater in the former than in the latter (Table VIII and fig. 9).

The maximum increase in spots was reached on August 11 in the early field and on August 28 in the medium-early sugar-beet field. The period of greatest increase in the disease is not its period of greatest destructiveness, however, as the plant is not immediately affected by the disease, some time being required for the leaves to be killed.

Prior to August 1, only isolated records of humidity were made in the early field,[1] but after this date continuous records of both humidity and temperatures in both fields were available for comparison (fig. 10).[2] The temperatures prevailing in the two sugar-beet fields were quite comparable, but the humidity was generally different. For instance, from August 2 to 23 the humidity remained above 60 for a longer time, and the maximum humidity was, as a rule, higher in the early than in the medium-early field; from August 23 to September 1 the maximum humidity was lower in the early than in the medium-early field; after the latter date strikingly lower, the difference ranging from 5 to 15 units; after September 5 the humidity remained above 60 for a shorter time in the former than in the latter field; but from September 6 to 21 the range of humidity in the two fields was much closer than during the periods previously mentioned.

The difference in the humidity of the two fields seemed to be due to the difference in the amount of foliage present. Early in the experiment the foliage was heavier in the early than in the medium-early field, but owing to an extremely severe infection, which developed between July 29 and August 13 (fig. 9), the relative proportion of foliage in the two fields was reversed after that period. As a result of this reversal, less moisture was retained and the humidity was lower in the early than in the medium-early field during September, and consequently at that time the relative increase in infection was less in the former than in the latter. Speaking more specifically, early in the experiment there was an average of 29 functional leaves per plant in the early field and 22 in the medium-early; on August 15 there was an average of 26 leaves per plant in both fields, while later on there were fewer per plant in the early than in the medium-early field. On the other hand, on August 13 there was an average of 23.5 infected leaves per plant, with an average of 710 spots per leaf in the early field, and on September 8 there was an average of 21.5 infected leaves per plant, with an average of 508.3 spots per leaf, in the medium-early field.

A comparison of the death rate of the leaves in the two fields before and after the disease appeared shows its destructiveness. For instance, in the early and medium-early fields, from July 7 to 29 and from July 2 to August 25, when no leaves were killed by the fungus, the death rate from normal causes was approximately one leaf per plant in three and four days, respectively; while from July 29 to August 15 and August 25 to September 19, when the disease was most severe in the two fields, the death rate averaged one leaf per plant in nine-tenths of a day and one and three-tenths days, respectively.

[1] These and the later continuous records indicate that prior to August 1 the humidity was generally higher in the early than in the medium-early field.

[2] The temperature records taken at the Weather Bureau station were included in the comparisons and were found to agree closely with those obtained in the two fields.

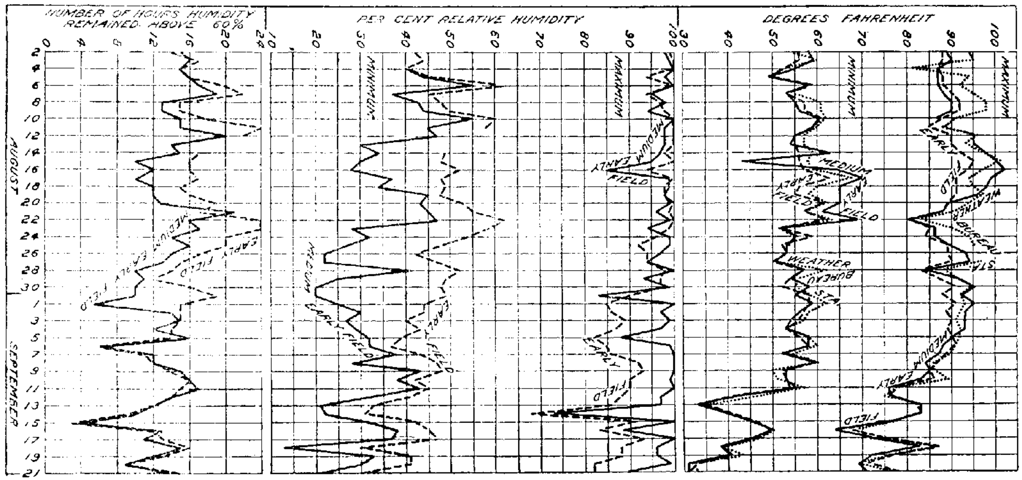

FIG. [illegible].—Curves of the maximum and minimum temperatures and relative humidities and the number of hours that the humidity remained above 60 from noon of the preceding to noon of the given day among the sugar-beet plants of a medium-early and an early field. For comparison, the maximum and minimum temperature records from the Weather Bureau station are included. August 2 to September 21, 1913, at Rocky Ford, Colo.

SUMMARY

(1) The life of the fungus *Cercospora beticola* overwintering in sugar-beet-top material varies with different environment. When exposed to outdoor conditions, the conidia die in from one to four months; but when kept dry live as long as eight months. The sclerotia-like bodies, which are more or less embedded in the tissues of the host, are more resistant than the conidia, living through the winter when slightly protected, as, for instance, in the interior of a pile of hayed sugar-beet tops or buried in the ground from 1 to 5 inches, and become a source of infection for the succeeding crop. Notwithstanding the difference in temperature and soil-moisture conditions, similar results from the overwintering experiments were obtained at Rocky Ford, Colo., and Madison, Wis.

(2) Climatic conditions and the development of the leafspot can be correlated only when all records are taken at the same relative positions, as shown by comparisons of the Weather Bureau records and the records taken among the plants and 5 feet above the field.

(3) The maximum temperature is much higher near the ground than 5 feet above early in the season, but the difference diminishes as the season advances.

(4) Throughout the season the maximum relative humidity was higher among the leaves than 5 feet above the field. Early in the season, while the plants were small, the humidity remained above 60 longer each day 5 feet above the field than among the plants near the ground; but after the plants attained a good size this condition was reversed. Because of this difference, only records collected among the leaves should be considered in correlating climatic conditions and conidial production and infection.

(5) The effect of rainfall and irrigation on the increase of relative humidity and its duration is apparently much the same.

(6) Thermal tests with artificial cultures showed (a) that exposure to constant temperatures of 35° and 36° C. is fatal to the growth of the fungus; (b) that growth occurred when cultures after exposure for 3 days to either of these temperatures were changed to 30.8°, and also when they were held at either for 8 hours and then at 20° for 16 hours; and (c) that a temperature of 40.5° was fatal in all combinations tested.

(7) Temperature and relative humidity influence the production of conidia and infection in much the same way. A temperature of 80° or 90° F., with a night minimum preferably not below 60°, is most favorable to conidial production, while it is checked by a temperature of 100° or higher and greatly checked by a range from below 50° to 80°. A maximum humidity ranging above 60 for not less than 15 to 18 hours each day induces a good growth of the fungus.

(8) Because of the higher humidity on the lower than on the upper surface of the leaf, the conidia are generally more abundant on the lower surface of the spots, but because of the action of rain and wind they disappear more rapidly from the upper surface.

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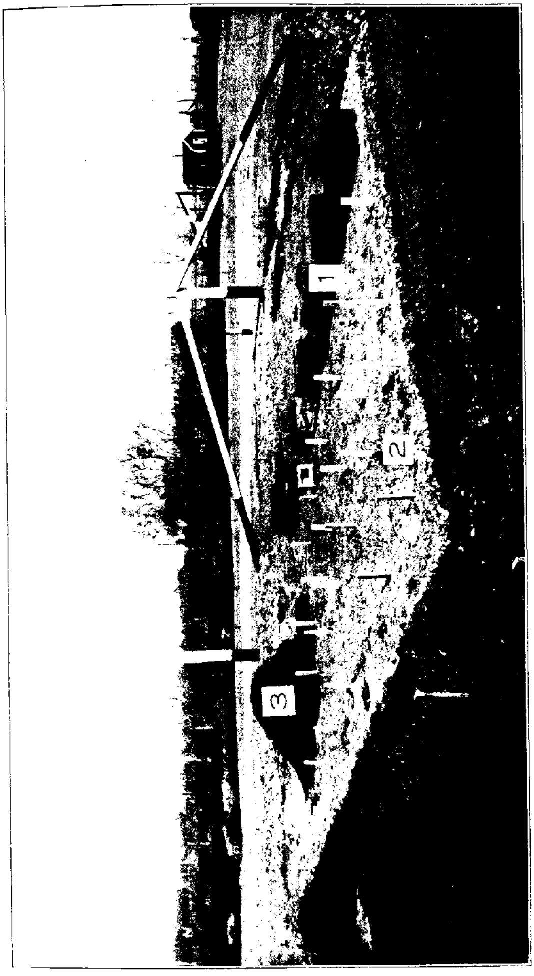
PLATE III

Cercospora beticola: Overwintering tests on the experimental field at Rocky Ford, Colo., during 1912–13:

Sugar-beet leaves infected with *Cercospora beticola* (*1*) stored in soil in boxes, (*2*) buried in the ground at different depths from 1 to 8 inches, and (*3*) left exposed above the ground in a pile of hayed sugar-beet tops.


1
2
3

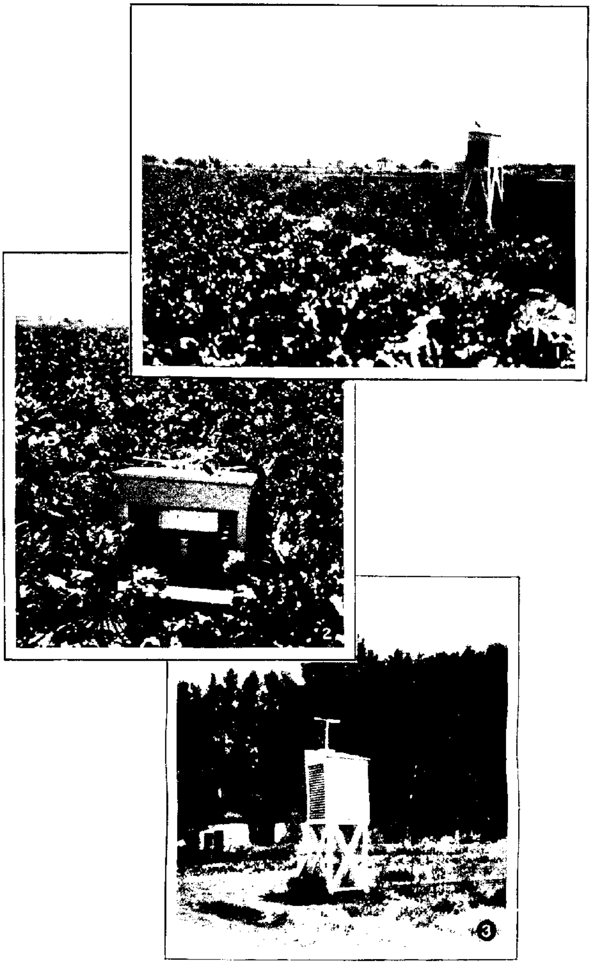


PLATE IV

Field stations for the collection of weather data at Rocky Ford, Colo., in 1913:

Fig. 1.—Weather shelter, anemometer, and rain gauge at edge of sugar-beet field.

Fig. 2.—Weather shelter among beet plants, showing hygrothermograph and cog psychrometer.

Fig. 3.—Weather shelter of the local Weather Bureau station about 3 miles from sugar-beet field.

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